PB80-213085

Chemical and Biological Treatment of Thermally Conditioned Sludge Recycle Liquors

Burgess and Niple Ltd.
Columbus, OH

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Jun 80

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-80-020

2.

3. RECIPIENT'S ACCESSION NO.
PB80 213085

4. TITLE AND SUBTITLE
CHEMICAL AND BIOLOGICAL TREATMENT OF THERMALLY CONDITIONED SLUDGE RECYCLE LIQUORS

5. REPORT DATE
June 1980 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Burgess & Niple, Limited
Consulting Engineers and Planners
Columbus, Ohio 43220

10. PROGRAM ELEMENT NO.
1BC821

11. CONTRACT/GRANT NO.
11010 DKI, SOS #1, Task A/17

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin.,OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final 1/69-3/78

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Office: B. Vincent Salotto (513) 684-7667

16. ABSTRACT

The objective of this research project was to demonstrate and evaluate the feasibility of treating undiluted heat treatment liquor prior to its rerouting back to the head of the sewage treatment plant. Chemical and biological treatment processes were studied. Chemical treatment was effected by the addition of hydrated lime followed by clarification both in bench-scale facilities and at full-scale in a 3200 gallon reactor. Biological treatment was achieved in a 2800 gpd high rate activated sludge pilot plant. Heat treatment liquor was generated by a Zurn heat treatment system, 16 gpm, at the Mentor, Ohio, wastewater treatment plant.

Results of the study indicate phosphorus and heavy metals were almost completely removed from the heat treatment liquor by the chemical lime addition, but BOD_5 and COD were only marginally removed. Biological system removed BOD_5 and COD much more efficiently. A comparison of total annual costs on a pollutant removal basis showed that biological treatment was more cost effective than chemical treatment.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Heat treatment liquor Sludge heat treatment Sludge thermal conditioning	Sludge treatment Sludge disposal Chemical conditioning Chemical treatment Biological treatment Heat treatment liquor recycle	13B

18. DISTRIBUTION STATEMENT
Release to Public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES

22. PRICE

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980-657-146/5697

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-80-020
June 1980

PB80-213085

Research and Development

EPA

Chemical and Biological Treatment of Thermally Conditioned Sludge Recycle Liquors

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SPRINGFIELD, VA 22161

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EPA-600/2-80-020
June 1980

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by

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Grant No. 11010 DKI

Project Officer

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OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This research provides additional data to aid in the evaluation of chemical and biological treatment systems for thermally conditioned sludge recycle liquor.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The objective of the research project was to demonstrate and evaluate the feasibility, effectiveness, and benefits of treating undiluted thermally conditioned sludge recycle liquors with chemical and biological treatment processes. Chemical treatment consisted of hydrated lime addition followed by clarification both in bench scale facilities and in a 120 cu m (32,000 gal) reaction clarifier. Biological treatment was achieved in a 10.9 cu m/day (2,880 gpd) high rate activated sludge plant. Recycle liquor for the project was generated from a Zurn heat treatment process with 87 cu m/day (16 gpm) capacity. The period of operation covered approximately a half a year for the concurrent study of both the chemical and biological systems.

Pollutant removal efficiencies were measured for: BOD_5, COD, ammonia and organic nitrogen, phosphorus, suspended solids, turbidity, color, and heavy metals. BOD_5 removal averaged 26% for the chemical system and 93% for the biological system. Color was reduced in both systems by at least 90%. In physical terms, the recycle liquor was a pale straw yellow to amber after chemical treatment and colorless to pale straw yellow after biological treatment.

The economics of recycle liquor treatment (including ultimate disposal of the resulting sludge) were evaluated for both systems. Total annual costs for treatment of recycle liquor generated from thermal conditioning of municipal sludges were: Chemical - \$0.012/kg (\$13.67/ton) of sludge and Biological -\$0.027/kg (\$29.78/ton) of sludge. However, on a pollutant removal basis, biological treatment is cost effective--total costs per tonne of BOD_5 removed - \$452 for chemical systems and \$370 for biological systems.

In addition to confirming previous laboratory and pilot scale studies, the report also includes: a thermal conditioning system process description, material and energy balances, characterization of recycle liquors, K-rate and cell growth coefficient studies, and design conditions for the chemical and the biological treatment facilities.

This report was submitted in fulfillment of Grant No. 11010 DKI by Lake County, Ohio, under the sponsorship of the U.S. Environmental Protection Agency. The report was prepared by Burgess and Niple, Limited, for Lake County after the subgrantee had completed the research study at the Mentor, Ohio, Sewage Treatment Plant. This report covers the period May 1975 to December 1978, and work was completed as of March 1979.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

average	avg
five day biochemical oxygen demand	BOD_5
British thermal unit	BTU
chemical oxygen demand	COD
cubic foot (feet)	cu ft
cubic feet per minute	cfm
cubic meter	cu m
degree Celsius	°C
degree Fahrenheit	°F
diameter	dia
endogenous decay coefficient, base 10	k
feet (foot)	ft
food to microorganism ratio	F/M
gallon(s)	gal
gallons per day	gpd
gallons per minute	gpm
gallons per hour	gph
horsepower	HP
hour(s)	hr
jackson turbidity units	JTU
joules	J
kilowatt hour	kwh
kilogram(s)	kg
kilometer	km
liter	l
metric ton	tonne
microgram(s) per liter	ug/l
milligram(s) per liter	mg/l
million gallons per day	MGD
minute(s)	min
mixed liquor suspended solids	MLSS
mixed liquor volatile suspended solids	MLVSS
nephelometric turbidity units	NTU
percent	%
platinum-cobalt color	Pt-Co
pound(s)	lb
pounds per square inch	psi
side water depth	SWD
square foot (feet)	sq ft
square meter	sq m
suspended solids	SS

LIST OF ABBREVIATIONS AND SYMBOLS (continued)

standard cubic foot (feet)	scf
standard cubic feet per minute	scfm
temperature	temp
total dissolved solids	TDS
total suspended solids	TSS
total dynamic head	TDH
total solids	TS
volatile solids	VS
waste activated sludge	WAS
weight	wt
year(s)	yr

SYMBOLS

cadmium	Cd
calcium hydroxide (hydrated lime)	$Ca(OH)_2$
calcium oxide (quicklime)	CaO
iron	Fe
lead	Pb
nickel	Ni
nitrogen	N
phosphorus	P
zinc	Zn

ACKNOWLEDGEMENTS

Burgess & Niple, Limited, Consulting Engineers would like to thank Mr. Robert Alban, Lake County Sanitary Engineer and Mr. Gary Kron, Project Coordinator for their assistance and cooperation throughout the administration of this grant.

We would especially like to thank Mr. Lee Friedabaugh, Superintendent of the Greater Mentor wastewater treatment plant and his staff for their efforts and patience in the operation of the heat treatment system and the associated research facilities. Special thanks are also due to Ms. Robin Taylor and Mr. Clarence Hiller of the Greater Mentor wastewater treatment plant laboratory who collected and analyzed many of the samples which form the basis of this research.

The project officer for the U.S. Environmental Protection Agency Municipal Environmental Research Laboratory (Cincinnati, Ohio) was Mr. B. Vincent Salotto, Chemist, Ultimate Disposal Section, Wastewater Research Division. During the early phase of the grant, the project officer was Dr. Joseph B. Farrell, Chief, Ultimate Disposal Section, Wastewater Research Division, MERL, USEPA. Their direction and assistance were much appreciated during the study.

Randall Wilson and Greg Knapp of Burgess & Niple, Limited contributed an extra effort in conducting extensive laboratory analyses for this project. Kay Wilson was responsible for typing the final manuscript.

SECTION I

INTRODUCTION

A number of municipal wastewater treatment facilities in the United States use thermal conditioning as a sludge processing method. A by-product of this process is a highly concentrated recycle liquor which is often returned to the main treatment facilities. Substantial quantities of BOD_5, nitrogen, phosphorus, and solids are solubilized in the thermal conditioning process and remain in the recycle stream. Although the volume of the recycle stream is small, its effect on the treatment plant is significant. Additional treatment demands by recycle liquors may result in overloading for those plants without sufficient excess capacity to accommodate these supplemental loads. For other plants that have not yet reached their design loadings, recycle liquor loads may force premature expansions.

Although much research has been conducted concerning optimum processing parameters for heat treatment systems, additional study devoted to the evaluation of recycle liquor treatment has been needed. To that end, this report addresses the operation and expected performance of separate treatment facilities for recycle liquor using both chemical and biological processes.

SECTION II

CONCLUSIONS

1. Chemical treatment of thermally conditioned sludge recycle liquors with hydrated lime was explored as a method of reducing their impact on wastewater treatment plants. Laboratory jar tests were performed to evaluate pollutant reductions at pH 8.5, 9.5, 10.5, and 11.5. The solutions were flocculated for 30 min and then allowed to settle for 60 min. The resulting supernatants were tested. The results of these analyses were:

    a. Lime dosages of about 1.6 kg CaO per 1,000 l (13.4 lb CaO per 1,000 gal) were required to achieve a pH of 10.5.

    b. BOD_5 and COD levels were marginally reduced by lime treatment. The greatest removals occurred at pH 11.5. At that pH, maximum BOD_5 reductions were 35% with treated effluents in the range of 1,150-3,300 mg/l BOD_5. Reductions of 11-38% were achieved with treated effluents in the range of 1,900-11,800 mg/l COD.

    c. Lime treatment was effective in removing phosphorus from recycle liquor. Initial phosphorus concentrations were reduced from an average of 270 mg/l P to less than 3 mg/l P at pH's exceeding 8.5 for an average phosphorus removal of 99%. In one full scale test, phosphorus removal of 96% was achieved.

    d. Chemical treatment with lime achieved average ammonia nitrogen reductions from 129 mg/l to 95 mg/l at pH 9.5 and greater. Average organic nitrogen reductions from 122 mg/l to 38 mg/l at pH 11.5 were achieved.

    e. Average suspended solids removals from 475 mg/l to 27 mg/l were achieved with lime clarification at pH 9.5 and greater.

    f. Turbidity and color removals from recycle liquor were also successful using chemical treatment with lime. Color was reduced from initial average concentrations of 4,250 Pt-Co color units to an average of 380 Pt-Co color units at pH 11.5. Visually, the treated liquor retained a yellow to amber tint. Average turbidity reductions were from 100 NTU to 3 NTU at pH 11.5.

g. Heavy metals such as cadmium, trivalent chromium, copper, lead, nickel, and zinc all form hydroxides with lime that are relatively insoluble at alkaline pH's. The data show that removal of the metals studies from recycle liquor is essentially constant at any level of lime treatment above pH 8.5. Average concentrations before and after treatment were as follows: cadmium, 300 ug/l to 15 ug/l; chromium, 800 ug/l to 26 ug/l; copper, 500 ug/l to 17 ug/l; lead, 1,100 ug/l to 160 ug/l; nickel, 500 ug/l to 37 ug/l; and zinc, 900 ug/l to 34 ug/l.

2. Biological treatment of thermally conditioned sludge recycle liquors with an activated sludge process was explored as another method of reducing the liquor's impact on wastewater treatment plants.

An activated sludge process operated in the high rate mode was used to evaluate biological treatment. Operating parameters were: mean cell residence time 1.3 days, organic loading of 1.6-2.4 kg BOD_5 per day/cu m (100-150 lb BOD_5 per day/1,000 cu ft), 4,000-5,000 mg/l MLSS and F/M of 0.4 to 1.0.

a. BOD_5 reductions averaged 93% with influent concentrations of 1,500-3,500 mg/l. Effluent BOD_5 concentrations ranged from 10-560 mg/l.

b. COD reductions averaged 76% with influent concentrations of 2,800-7,600 mg/l. Loadings to the system were in the range of 2.5-4.5 kg COD/cu m/day. Effluent COD concentrations ranged from 340-1,930 mg/l.

c. Ammonia and organic nitrogen were approximately removed as predicted by the nutrient requirements for heterotrophic bacteria, i.e., 6 parts nitrogen per 100 parts BOD_5 removed.(24) The sum of ammonia and organic nitrogen removed was 6.2 kg N per 100 kg BOD_5. Ammonia nitrogen and organic nitrogen removals averaged 66% and 62%, respectively.

d. Total phosphorus reductions of 5 kg P per 100 kg BOD_5 were achieved. This did not confirm earlier research by Corrie(23) and Erickson(22) nor the nutrient requirements for heterotrophic bacteria shown by Helmers,(24) i.e., 1 part phosphorus per 100 parts BOD_5 removed. Phosphorus removal averaged 89%.

e. Suspended solids reductions averaged 88% with influent concentrations from 600-2,000 mg/l.

f. The average endogenous decay coefficient (k-rate) for recycle liquor generated from the Zurn process was determined to be 0.13 day^{-1}. Therefore, the aeration requirements for this waste would be approximately the same as for ordinary domestic sewage.

g. The cell growth coefficient for the recycle liquor generated for this project was determined to be 0.49 kg volatile solids produced per kg BOD_5 removed.

3. The total annual cost of chemical treatment of recycle liquor generated from a 2.2 cu m/second (50 MGD) wastewater treatment plant is \$226,800 per year [\$0.012/kg (\$13.67/ton)] of thermally conditioned sludge] including capital and operation and maintenance cost. This cost is based on lime treatment using hydrated lime, a reaction clarifier, transportation, and land application of the resulting lime sludge (without dewatering). Additional treatment costs due to incomplete pollutant removal by chemical treatment were not included.

4. The total annual cost of biological treatment of recycle liquor generated from a 2.2 cu m/second (50 MGD) wastewater treatment plant is \$493,900 per year [\$0.027/kg (\$29.78/ton)] of thermally conditioned sludge] including capital and operation and maintenance cost. This cost is based on a high rate activated sludge process, anaerobic digestion of the resulting sludge, transportation, and land disposal of the liquid sludge. No additional treatment costs for the recycle of treated recycle liquor were computed.

5. Comparison of total annual costs on a pollutant removal basis shows that biological treatment is more cost effective than chemical treatment. Since the removals for phosphorus and suspended solids were essentially the same with either process, treatment costs were compared based on annual removals of BOD_5. Assuming 35% BOD_5 reduction for chemical treatment and 93% BOD_5 reduction for biological treatment, the costs for recycle liquor treatment were:

   Chemical treatment \$451.79/tonne BOD_5 removed
   Biological treatment \$370.09/tonne BOD_5 removed

SECTION III

BACKGROUND

GENERAL

The Willoughby-Mentor wastewater treatment plant, Mentor, Ohio, was placed in operation in September 1965. The plant provided for influent pumping and primary treatment with the addition of chemicals followed by discharge to Lake Erie. Sludge disposal was by anaerobic digestion and vacuum filtration. Subsequent to the original treatment plant construction, the state regulatory agency determined that all plants discharging into Lake Erie should provide secondary treatment including phosphorus removal. Accordingly, plans were begun to upgrade the primary treatment facilities.

In 1968, the need to investigate alternate methods of sewage sludge processing and disposal became apparent. The heat treatment process was emerging as an attractive process alternative and was considered in detail for incorporation into the Willoughby-Mentor treatment plant. On September 20, 1968, a formal application was made to the Federal Water Pollution Control Administration requesting funds for the construction and demonstrative operation of the "Porteous Process" for heat treatment of sludge. A grant was offered by the FWPCA dated December 20, 1968, and was accepted by resolution of the Board of County Commissioners on December 23, 1968.

Subsequent to the grant award, detailed construction drawings and specifications were prepared and the project was bid. The Erie Energy Division of Zurn Industries was ultimately selected to construct and demonstrate an experimental innovative modification to the Porteous process at the Willoughby-Mentor wastewater treatment plant. The unit was planned to be incorporated into the expanded primary/secondary treatment plant as described in the following section. Construction was begun in April 1971, and was completed in April 1973.

WILLOUGHBY-MENTOR WASTEWATER TREATMENT FACILITIES

The expanded Willoughby-Mentor wastewater treatment plant utilizes an activated sludge biological treatment system. Figure 1 shows the plant site plan and general wastewater flow. The biological treatment is preceded by comminution, grit

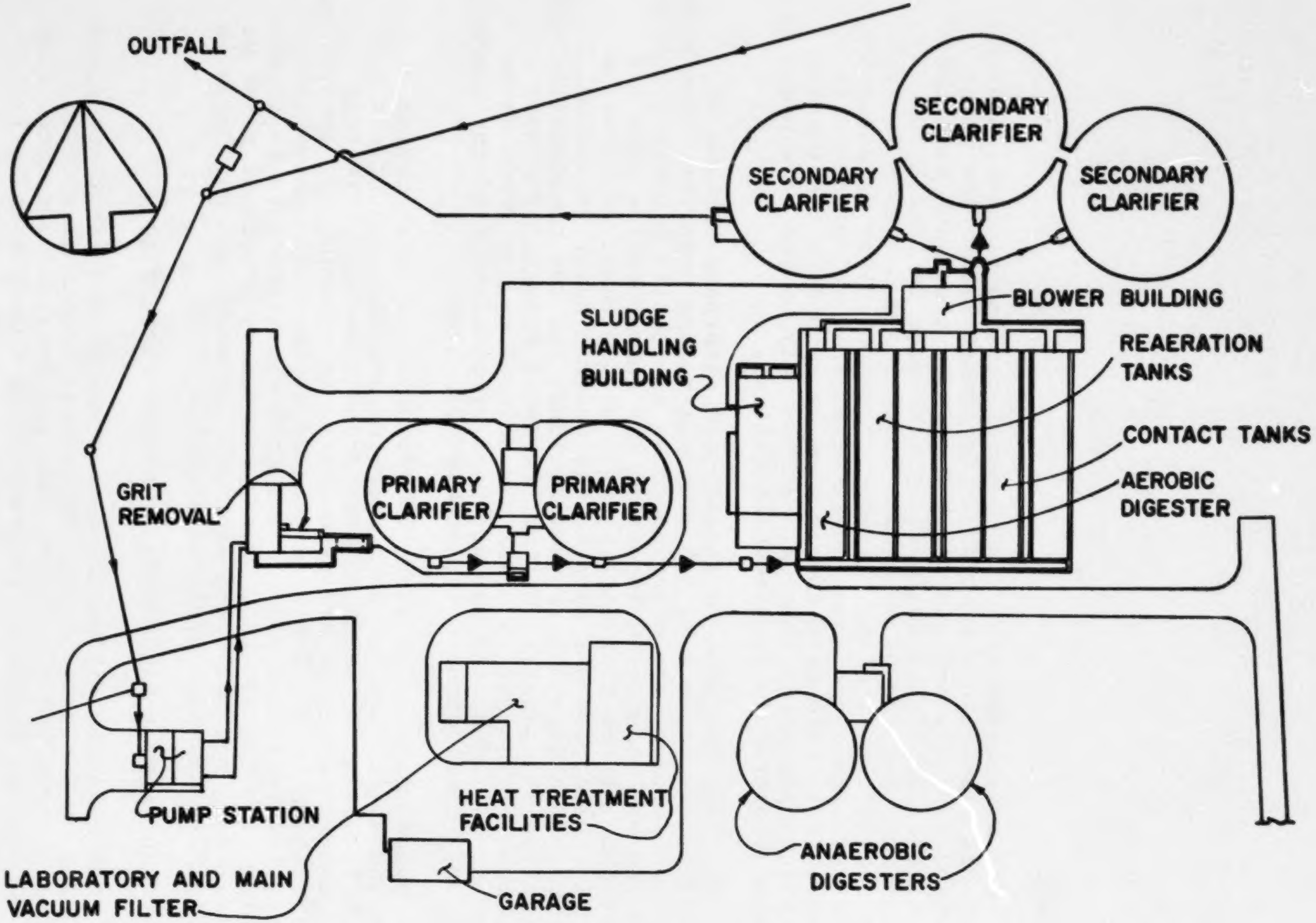
OUTFALL
SECONDARY CLARIFIER
SECONDARY CLARIFIER
SECONDARY CLARIFIER
BLOWER BUILDING
SLUDGE HANDLING BUILDING
REAERATION TANKS
CONTACT TANKS
AEROBIC DIGESTER
GRIT REMOVAL
PRIMARY CLARIFIER
PRIMARY CLARIFIER
PUMP STATION
HEAT TREATMENT FACILITIES
ANAEROBIC DIGESTERS
LABORATORY AND MAIN VACUUM FILTER
GARAGE

Figure 1. Willoughby-Mentor wastewater treatment plant site plan.

removal, and primary sedimentation and is followed by disinfection. Phosphorus removal is accomplished by chemically treating the wastewater within the biological treatment system. Design data for the treatment plant are summarized in Table 1.

TABLE 1. DESIGN DATA - WASTEWATER
WILLOUGHBY-MENTOR WASTEWATER TREATMENT PLANT

Description	Capacity
Design Flow	30,280 cu m/day (8 MGD)
Average Flow	18,900 cu m/day (5 MGD)
Design BOD Loading @ 200 mg/l BOD_5	6,056 kg/day (13,350 lb/day)
Design Solids Loading @ 240 mg/l SS	7,267 kg/day (16,020 lb/day)

Sludges produced during the treatment of the wastewater include primary sludge and waste activated sludge. Facilities are provided for anaerobic and aerobic digestion, chemical conditioning, heat treatment, and dewatering the sludges. A reactor clarifier is provided for chemically treating supernatants from the sludge treatment processes with hydrated lime before the liquid is discharged back into the wastewater treatment system.

The principal flow patterns between the sludge treatment processes are shown schematically on Figure 2. The principal flow pattern for the primary sludge is thickening in the sludge holding tank, heat treatment, thickening in the decant tanks, and vacuum filtration.

Waste activated sludge is processed by aerobic digestion prior to gravity sludge dewatering and/or land application. Waste activated sludge also can be processed with primary sludge by anaerobic digestion followed by vacuum filtration and landfill.

Sludge processing by thermal conditioning has been limited to primary sludge although primary-waste activated sludge mixtures could be processed.

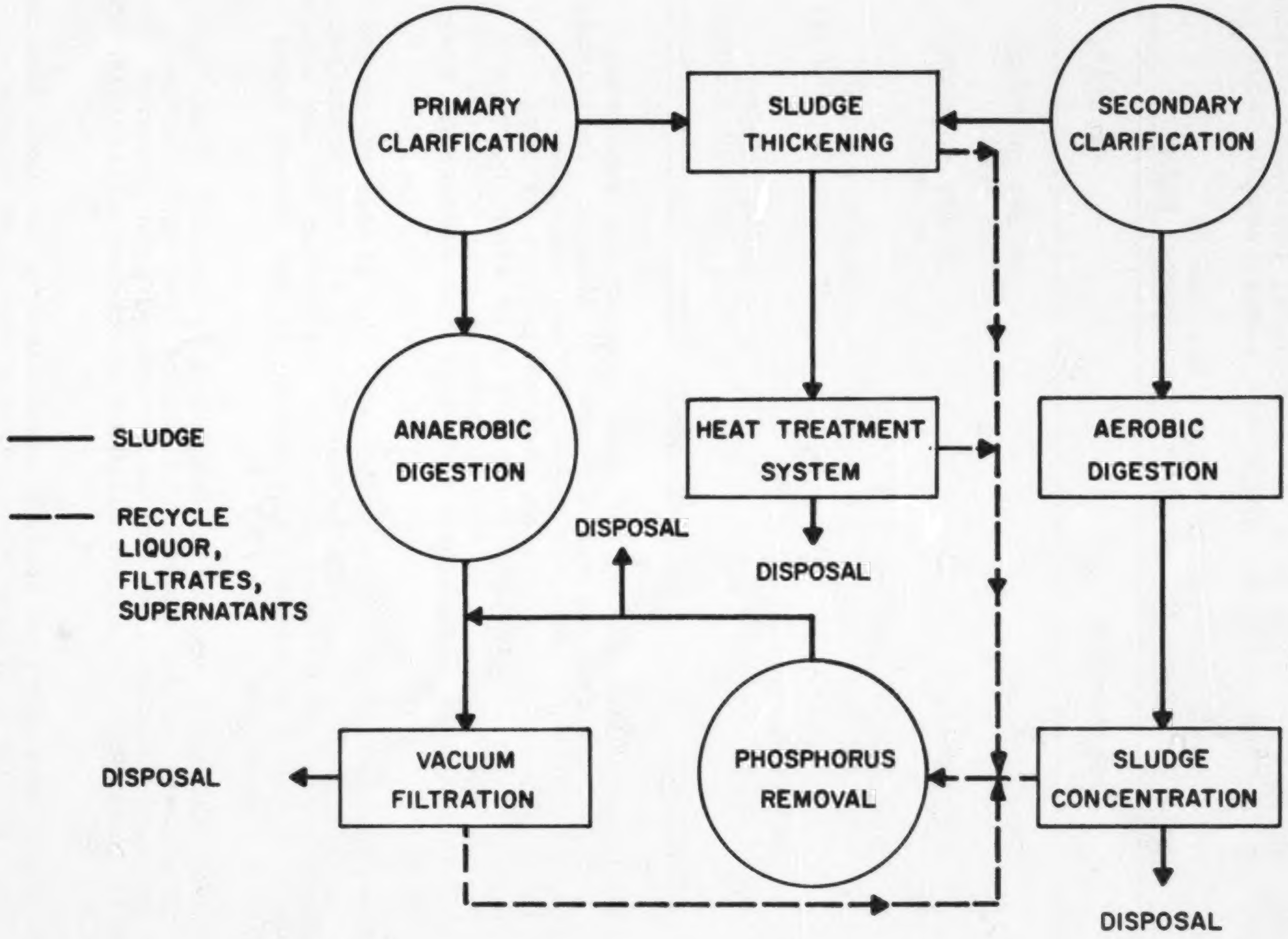
PRIMARY CLARIFICATION
SLUDGE THICKENING
SECONDARY CLARIFICATION
ANAEROBIC DIGESTION
HEAT TREATMENT SYSTEM
AEROBIC DIGESTION
DISPOSAL
DISPOSAL
VACUUM FILTRATION
PHOSPHORUS REMOVAL
SLUDGE CONCENTRATION
DISPOSAL
DISPOSAL
SLUDGE
RECYCLE LIQUOR, FILTRATES, SUPERNATANTS

Figure 2. Sludge handling flow schematic.

Design data for the sludge handling facilities are summarized in Table 2.

TABLE 2. DESIGN DATA - SLUDGE HANDLING
WILLOUGHBY-MENTOR WASTEWATER TREATMENT PLANT

Description	Capacity
Aerobic Digester	1,246 cu m (44,000 cu ft)
Sludge Concentrators for WAS	7.6 cu m/hr (2,000 gph)
Anaerobic Digesters, (2), total	3,478 cu m (122,840 cu ft)
Holding-Thickening Tank, volume	84 cu m (2,980 cu ft)
Vacuum Filter, area	12.3 sq m (132 sq ft)
Loading rate @ 30% dry solids	40 kg/sq m/hr (8 lb/sq ft/hr)
Heat Treatment, design flow	3.6 cu m/hr (16 gpm)
Process Temperature, max	204°C (400° F)
Process Pressure, max	1.9 x 10^6 newton/sq m (275 psi)
Vacuum Filter	5.9 sq m (63 sq ft)
@ 30% dry solids	52 kg/sq m/hr (10.6 lb/sq ft/hr)
Phosphorus Removal Facilities	
Reaction Clarifier	
Design Flow	22.8 cu m/hr (6,000 gph)
Lime Feed, range	13.6-136 kg/hr (30-300 lb/hr)

MAINTENANCE AND START-UP DIFFICULTIES

Construction of the sludge heat treatment facilities was completed in April 1973. Acceptance tests began in May 1973 and were completed on December 30, 1975. During this period, numerous difficulties were encountered. Problems were accentuated by the construction of the secondary treatment facilities. Because the grit removal facilities were either under construction or inoperable, severe difficulties were encountered with large stones and rags plugging both the sludge thickener drawoff line and heat treatment feed lines. Secondly, the stones caused mechanical problems with the sludge grinders and high pressure pump rotors and stators. Numerous test runs were required because of the failure of the heat treatment system to operate within the allowed natural gas requirements and vacuum filter cake production rates. Finally, a considerable period of time was required to evaluate vacuum filter cloths and to determine the proper operation of the vacuum filter system.

SECTION IV

THERMAL CONDITIONING PROCESS DESCRIPTION

GENERAL

The purpose of sludge heat treatment is to stabilize and condition primary and waste activated sludges so that the need for additional chemical treatment in the dewatering process is either reduced or eliminated. Thermal conditioning can also be used in place of other sludge stabilizing systems such as aerobic or anaerobic digesters. Three common thermal treatment systems are: Zimpro process, BSP-Porteous process, and Neptune-Nichols or Farrer process. These systems are compared with the Zurn process in Table 3. The Neptune-Nichols and Zurn processes are essentially the same and do not use direct steam injection into the sludge. Instead, sludge is heated indirectly with a heat exchanger. The BSP-Porteous and Zimpro processes use direct steam injection. Zimpro is the only system that uses sludge to sludge heat exchangers and direct air injection.

A schematic flow diagram for the Zurn sludge heat treatment unit is shown on Figure 3. Either raw primary or waste activated sludge is transferred to the sludge holding tank by sludge pumps. This tank is equipped with a gravity thickening mechanism, which is used to further concentrate the sludge before it is pumped to the heat treatment unit. Two variable speed, centrifugal pumps take suction from the holding tank sludge well and transfer the thickened sludge to the heat treatment unit grinders and high pressure sludge pumps. The thickened sludge is ground to a fine suspension before it flows into the high pressure sludge pumps. The discharge pressure of these pumps must be sufficiently high to prevent the water in the reactor and heat exchanger from flashing to steam during the heat treatment process. The untreated sludge is then heated (150-200° C) in the sludge heat exchanger (132 sq m of tubes with heat transfer coefficient, U=469 J/sec-sq m-°C [84 BTU/hr-sq ft-°F]) by hot water circulating countercurrently with the sludge. Heated sludge flows into the reactor where it is retained for approximately 1 hr. From the reactor, the treated sludge flows through the sludge heat exchanger (152 sq m of tubes with U=614 J/sec-sq m-°C [110 BTU/hr-sq ft-°F]) where heat is recovered by the hot water circulating system and the sludge is cooled. Downstream of the sludge cooler is the sludge flow control valve which is automatically regulated by the reactor sludge level and maintains

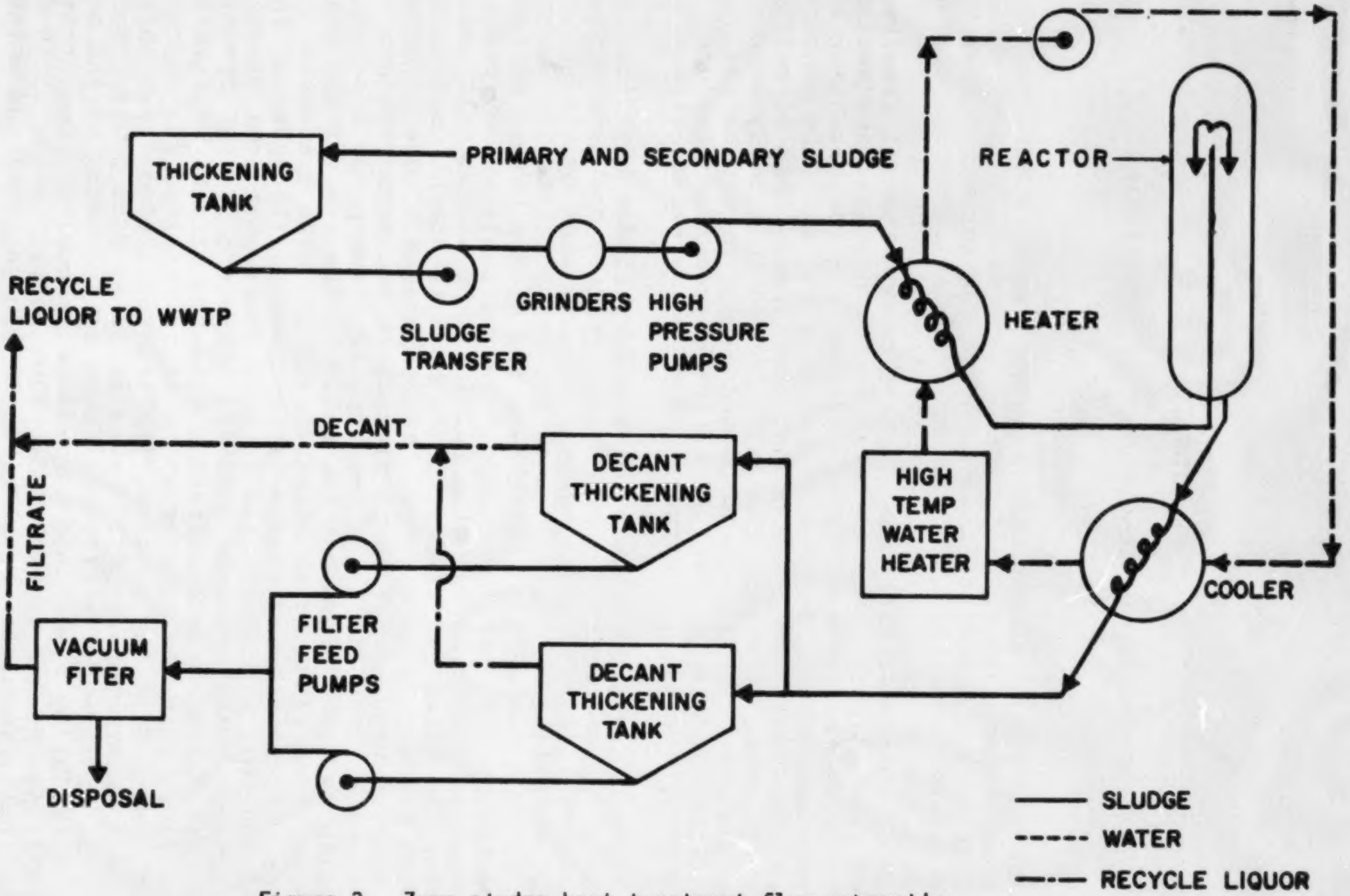
PRIMARY AND SECONDARY SLUDGE
THICKENING TANK
REACTOR
RECYCLE LIQUOR TO WWTP
SLUDGE TRANSFER
GRINDERS
HIGH PRESSURE PUMPS
HEATER
DECANT
FILTRATE
DECANT THICKENING TANK
HIGH TEMP WATER HEATER
COOLER
FILTER FEED PUMPS
VACUUM FITER
DECANT THICKENING TANK
DISPOSAL
SLUDGE
WATER
RECYCLE LIQUOR

Figure 3.. Zurn sludge heat treatment flow schematic.

TABLE 3. THERMAL CONDITIONING SYSTEMS

Parameter	Zurn	Neptune-Nichols	BSP-Porteous	Zimpro
Air Injection	No	No	No	Yes
Residence Time				
@ Maximum temp (min)	45-60	30	30-60	20-30
Heat Supply	Hot water boiler	Hot water boiler	Steam generator	Steam generator
Heat Transfer	Heat exchanger: hot water recirculation	Heat exchanger: hot water recirculation	Steam injection	Steam injection
Reactor Sludge Waste Heat Recovery	Heat exchanger water heating	Heat exchanger water heating	Heat exchanger water heating	Heat exchangers sludge to sludge
Operating Temp (°C)	150-204	202	177-204	150-204

backpressure on the reactor. Cooled, treated sludge then is transferred to the either of two decant tanks for storage. Each of these tanks is equipped with a gravity thickening device to further concentrate the sludge before it is applied to the vacuum filter. Supernatant from the decant tanks and filtrate from the vacuum filter are pumped to the phosphorus removal process (lime treatment) and/or recycled to the aeration influent.

MATERIAL AND ENERGY BALANCES

Material Balance

Thermal conditioning improves sludge dewaterability, but generates a highly concentrated recycle liquor as a by-product. Although the volume of the liquor is small when compared to the main plant flow, the recycle has a substantial impact on the treatment facilities. In order to quantify the impact of the Zurn thermal conditioning system on the Willoughby-Mentor wastewater treatment plant, a material balance was constructed. The reactor was operated at 193 °C with a sludge residence time of 60 min for two 16 hr runs. The vacuum filter output was weighed on a truck scale and grab samples of the cake were taken from two points on the drum at 15 min intervals. Sludge flows were measured by timing the filling of tankage and by flow meters. Figure 4 shows the material balance for the Zurn system based on processing primary sludge at 6.2% solids as an average of the two trial runs.

As the sludge passes through the reactor, 5% of the solids are solubilized. This amounts to about a 120% increase in dissolved solids. These dissolved solids, along with the suspended solids in the decant tank supernatant and vacuum filter filtrate, are recycled back through the treatment plant. These recirculating solids represent about 17% of the total solids processed by the thermal conditioning system. Over half of this recirculating solids load is comprised of dissolved solids.

Energy Balance

Ewing, Almgren, and Culp(2) investigated costs associated with thermal conditioning systems of various sizes. They compiled cost information for direct costs including operation and maintenance costs for many heat treatment systems operating in the United States. Their average direct costs for a 4,535 kg/day (5 ton/day) thermal conditioning system included an energy cost for pumping, heating, and dewatering. These costs are summarized on page 16 using unit costs of $2.80 per million BTU for fuel and $0.03/kwh for power.

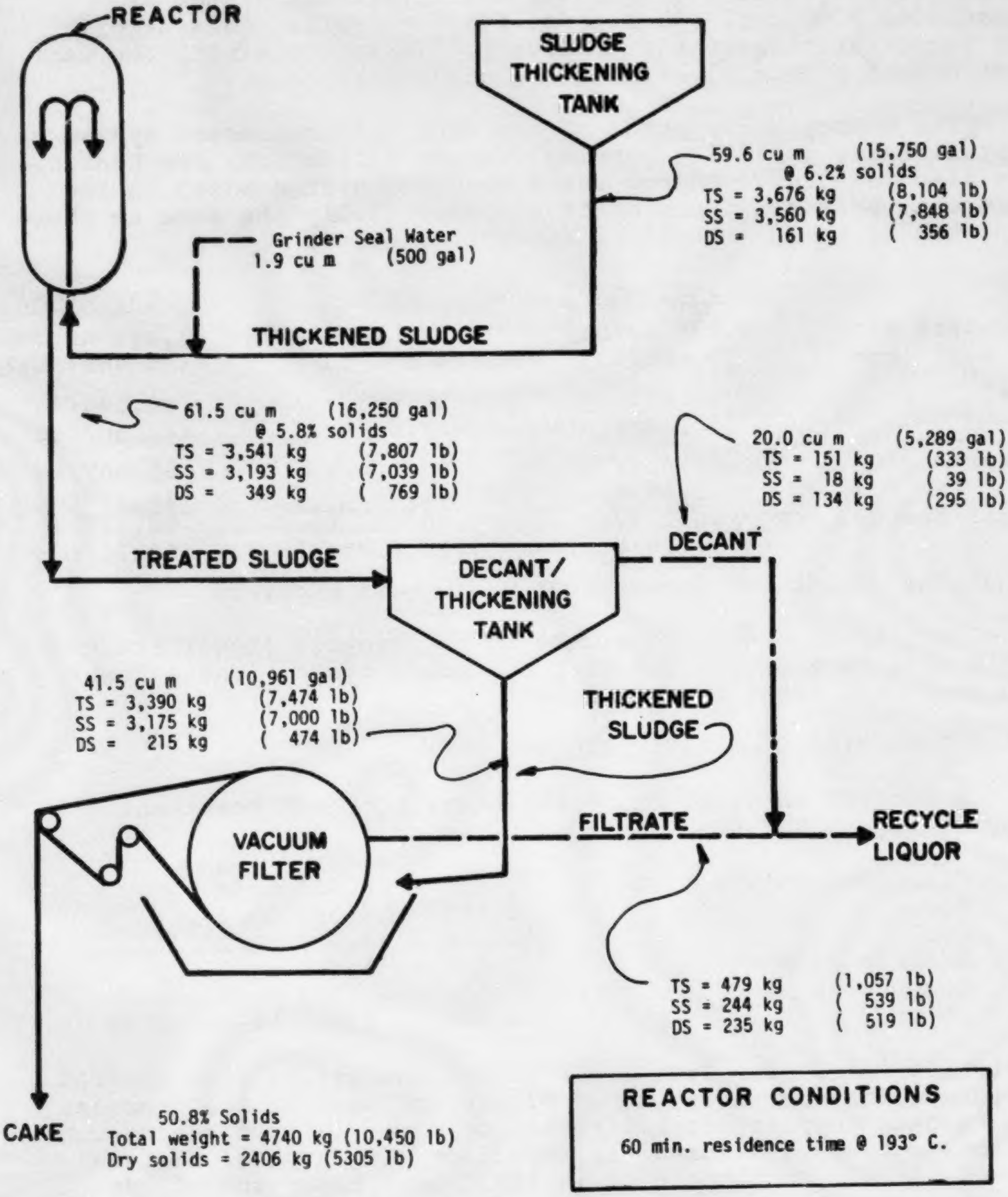
REACTOR
SLUDGE THICKENING TANK
59.6 cu m (15,750 gal) @ 6.2% solids
TS = 3,676 kg (8,104 lb)
SS = 3,560 kg (7,848 lb)
DS = 161 kg (356 lb)
Grinder Seal Water 1.9 cu m (500 gal)
THICKENED SLUDGE
61.5 cu m (16,250 gal) @ 5.8% solids
TS = 3,541 kg (7,807 lb)
SS = 3,193 kg (7,039 lb)
DS = 349 kg (769 lb)
20.0 cu m (5,289 gal)
TS = 151 kg (333 lb)
SS = 18 kg (39 lb)
DS = 134 kg (295 lb)
TREATED SLUDGE
DECANT
DECANT/ THICKENING TANK
41.5 cu m (10,961 gal)
TS = 3,390 kg (7,474 lb)
SS = 3,175 kg (7,000 lb)
DS = 215 kg (474 lb)
THICKENED SLUDGE
VACUUM FILTER
FILTRATE
RECYCLE LIQUOR
TS = 479 kg (1,057 lb)
SS = 244 kg (539 lb)
DS = 235 kg (519 lb)
CAKE
50.8% Solids
Total weight = 4740 kg (10,450 lb)
Dry solids = 2406 kg (5305 lb)
REACTOR CONDITIONS
60 min. residence time @ 193° C.

Figure 4. Zurn thermal conditioning system material balance.

Swets, Pratt, and Metcalf(3) reported energy costs for a larger 63,490 kg/da (70 ton/day) heat treatment system at Kalamazoo, Michigan. Their cost for fuel reflected a credit for incinerator waste heat recovery. These costs with the same unit prices previously stated are summarized below.

The energy consumption of the Zurn heat treatment system at Mentor, Ohio, including pumping, vacuum filtration, and heating, was also measured. Energy costs were calculated based on the same unit prices. These costs are essentially the same as those reported by Ewing(2) and are summarized below.

	Ewing, et al	Zurn	Swets, et al
Facility Size	4,535 kg/day (5 ton/day)	3,628 kg/day (4 ton/day)	63,490 kg/day (70 ton/day)
Fuel	\$0.008/kg (\$7.18/ton)	\$0.009/kg (\$7.92/ton)	\$0.004/kg* (\$3.56/ton)
Power	\$0.006/kg (\$5.48/ton)	\$0.006/kg (\$5.39/ton)	\$0.007/kg (\$6.18/ton)
Total Energy	\$0.014/kg (\$12.66/ton)	\$0.014/kg (\$12.82/ton)	\$0.011/kg (\$9.74/ton)

*Includes credit for incinerator waste heat recovery

Additional energy requirements for recycle liquor treatment would also have associated fuel and power costs. These costs are presented later in this report.

CHARACTERISTICS OF RECYCLE LIQUOR

A general range of characteristics for heat treatment recycle liquor has been reported by Ewing(2) as:

Suspended Solids	100 - 20,000 mg/l
BOD_5	5,000 - 15,000 mg/l
COD	10,000 - 30,000 mg/l
Ammonia as N	400 - 1,700 mg/l
Phosphorus as P	150 - 200 mg/l
Color	1,000 - 6,000 Pt-Co units

Variation in recycle liquor concentrations arises from several factors: (a) concentration of sludge influent to the process; (b) reactor temperature and residence time; (c) processing conditions such as steam and air injection; (d) type of sludges processed; (e) settling time in the decant tank; and (f) dewatering conditions. These factors vary widely from one installation to another depending upon local processing needs. To illustrate the variation in recycle liquors, data from various thermal conditioning plants including Jackson Pike and Southerly in Columbus, Ohio, are presented in Table 4 along with data from Ewing(2) and Sherwood.(4)

TABLE 4. RECYCLE LIQUORS AT SEVERAL HEAT TREATMENT FACILITIES

	Jackson Pike Columbus, OH	Southerly Columbus, OH	Semboku, Sakai (Japan)[(2)]	Colorado Springs Colorado Springs, CO[(4)]
Sludge flow rate				
cu m/hr	41	36	10	36
(gpm)	180	160	45	158
Processing temp, °C	195°	191°	194°	204°
Reactor residence time, hr	0.37	0.4	0.75	0.5
Influent sludge, dry solids	2.3%	4.6%	4%	6%
Sludge mixture - primary/waste activated	50%/50%	30%/70%	N/A	N/A
Processing method	Zimpro	Zimpro	Porteous	Porteous
BOD_5, mg/l	4,000	8,000	5,847	3,800*
COD, mg/l	10,600	14,000	N/A	8,470*
Total solids, mg/l	5,900	12,210	7,191	3,120**
Suspended solids, mg/l	580	640	547	N/A
Ammonia nitrogen, mg/l	182	430	N/A	N/A
Organic nitrogen, mg/l	465	1,060	N/A	N/A
Phosphorus, mg/l	70	350	N/A	N/A

*Decant only
**Filtrate only
N/A denotes not available

The average characteristics of the recycle liquor used in this study are shown in Table 5. The reactor was operated at 150° C at about 3.6 cu m/hr (16 gpm) for a residence time of 60 min using primary sludge only.

TABLE 5. RECYCLE LIQUOR CHARACTERISTICS-Mentor, Ohio

	Average	Range
BOD_5, total, mg/l	3,330	2,550-3,850
BOD_5, soluble mg/l	2,430	2,100-3,500
COD, mg/l	6,860	6,000-8,050
Solids		
Total, mg/l	3,690	3,130-5,000
Suspended, mg/l	1,290	700-1,850
Ammonia nitrogen, mg/l	140	100-186
Organic nitrogen, mg/l	125	40-175
Phosphorus, mg/l	190	120-270
pH	5.1	4.8-6.2
Color, Pt-Co units	4,000	800-6,000

IMPACT OF RECYCLE LIQUOR

Substantial organic and solids loading to treatment facilities by recycle liquors from sludge thermal conditioning has been reported. At the Colorado Springs, Colorado wastewater treatment plant, an analysis of the impact due to the recycle of heat treated liquor has been made by Boyle and Gruenwald.(5) Their material balance on the heat treatment system showed that 21% of the BOD_5 and 30% of the suspended solids influent to the 30 MGD treatment plant were due to recycle liquor. They also noted an increase in the plant effluent color and turbidity. The final effluent averaged 60-100 Pt-Co color units and 10-20 JTU after the heat treatment system was started up.

Haug, et al(6) also reported that recycle liquor from the Los Angeles Hyperion plant would have a considerable impact upon the secondary treatment plant. Material balances showed a 30% increase in the oxygen demand on the aeration system would result from recycle liquor. This was considered unacceptable and further recycle liquor treatment studies were begun.

Surveys by Harrison(1) and Ewing(2) of various heat treatment systems indicated that substantial BOD_5 and suspended solids loads were due to recycle liquors. These loads expressed as a percentage of the total wastewater treatment plant loadings are summarized in Table 6. Recycle loads for the Mentor plant are also included. The Mentor loads are based on an average

BOD_5 and TSS wastewater concentrations of 200 mg/l each, a plant flow of 0.22 cu m/second (5 MGD), a heat treatment flow of 87 cu m/day (16 gpm), and average recycle liquor concentrations.

TABLE 6. ADDITIONAL LOADING FROM RECYCLE LIQUORS AT SEVERAL INSTALLATIONS

	Recycle Loads* (%)	
	BOD_5	Suspended Solids
Gresham, Oregon	41	59
Vancouver, Washington	35	11
Kalamazoo, Michigan	35-40	-
Colorado Springs, Colorado	21	30
Portland, Oregon	16-28	16-28
Mentor, Ohio	7.2	2.8

* Based on total plant design loads

The imposition of additional organic and solids loads from heat treatment facilities to plant secondary systems may be even more significant than suggested in Table 6 due to the high soluble fraction of BOD and the colloidal nature of a large portion of the suspended solids. It follows that the major impact of recycle liquors has been the premature commitment of reserve capacities and treatment problems.(1,2,5)

SECTION V

CHEMICAL TREATMENT OF RECYCLE LIQUOR

GENERAL

Chemical treatment of thermally conditioned sludge recycle liquors with lime was explored as one method of reducing the impact on wastewater treatment plant. The primary interest was to reduce the high BOD_5 levels in the recycle liquor. Other goals of chemical treatment were to reduce the levels of ammonia nitrogen, phosphorus, suspended solids, turbidity, color, and heavy metals.

Lime has been used extensively in wastewater treatment processes primarily because of its low cost.(7) The results of several previous studies on the application of lime treatment for the removal of phosphate, color, suspended solids, BOD_5, and nitrogen have been reported in the literature. Pilot plant work by Eldridge(8) on tannery wastes treatment with lime determined BOD_5 and suspended solids removals. Buzzell and Sawyer(9) investigated pollutant removals from raw municipal wastewater using chemical treatment with lime. Lime treatment of raw wastewater was also reported by Horstkotte, et al.(10) Wilson, et al(11) and Haynes(12) reported lime studies by the kraft paper industry on the treatment of highly colored processing wastes. G. E. Bennett(13) investigated the effects of lime treatment on anaerobic digester supernatants using pilot plant facilities.

Recycle liquor treatment by the lime clarification process was selected for study in light of the results of studies reported in the literature cited above. A reaction clarifier at the Willoughby-Mentor treatment plant was employed to evaluate the feasibility, effectiveness, and benefits of chemical treatment of recycle liquors with lime.

OPERATION AND SAMPLING

All of the recycle liquor treatment studies were conducted with supernatant from the treated sludge decant tanks. Problems with the vacuum filtration equipment prevented the production of filtrate from the dewatering of heat treated sludge. Decant liquor was produced from heat treating primary sludge at 150°C.

Bench scale studies on lime treatment were carried out concurrently with the full scale work. Only two runs were completed with the full scale lime clarifier because of the limited quantity of recycle liquor. The data presented, therefore, is primarily based on the bench scale lime treatment facilities.

Commercial grade hydrated lime with 73% calcium oxide was used for all lime treatment studies.

Bench Scale Tests

A standard jar testing apparatus was used for the bench scale tests. One percent hydrated lime slurries were slowly added with rapid mixing for five min. The treated liquor was flocculated for 30 min, followed by settling for 60 min. Clarified supernatant was siphoned off from the settled lime sludge to prevent agitation of the light floc.

Target pH values of 8.5, 9.5, 10.5 and 11.5 were used in the pilot scale studies. Initial liquor pH was approximately 5-6 as previously described. Lime requirements for neutralization of the heat treatment liquor have been summarized in Table 7.

TABLE 7. LIME DOSAGE REQUIREMENTS FOR NEUTRALIZATION OF RECYCLE LIQUORS

pH	Lime Dosage* kg CaO per cu m	lb CaO per 1,000 gal
8.5	1.1	9.1
9.5	1.5	12.2
10.5	1.6	13.4
11.5	1.8	15.3

* Expressed as 100% CaO.

The amount of lime required to raise the liquor to pH 9.5 is approximately ten times that required for normal sewage. Bennett(14) has reported lime dosage requirements of 6,000 mg/l commercial grade calcium hydroxide (3.4 kg CaO/cu m) to reach pH 10.7 with anaerobic digester supernatant which is approximately twice that observed for recycle liquor.

Full Scale

The 120 cu m (32,000 gal) reaction clarifier located at the wastewater treatment plant was designed to be used with anaerobically digested filtrates and supernatants as well as heat treatment recycle liquors. Lime was stored in a bin and discharged by gravity into two volumetric lime feeders (reciprocating plate type). A dissolving tank was located directly beneath each feeder and adjacent to the clarifier.

Hydrated lime was slurried in each of two 0.2 cu m (50 gal) dissolving tanks and fed by gravity through an open trough into the stirred reaction well of the clarifier. The process was designed to operate continuously. The rate of lime application could be controlled by changing the volumetric feed rates on each feeder. Recycle liquor was pumped into the reaction well of the clarifier near the point of slurry application. Figure 5 shows a schematic of the facilities.

Two factors prevented the proper use of the chemical treatment facility:

1. Hydrated lime was subject to frequent arching or bridging inside the storage bin. Upon collapse of the lime bridges, the volumetric feeders became inundated with lime.

2. The system was unable to function well on a batch basis. Heat treatment recycle liquor was not available in sufficient quantity to operate on a continuous basis.

The following lime transfer system modification should be incorporated into the facilities to circumvent the first problem outlined above. In addition to the existing vibrators mounted on the sloping section of the storage bin (designed to break up any bridging which may occur), the system should include horizontal augers to transfer the hydrated lime to the feeders. This will prevent "flooding" of the dissolving tanks.

The second problem arose because the vacuum filter system for dewatering thickened heat treated sludge was not used. Operational problems with the filter system existed that were beyond the scope of simple plant maintenance solutions.

RESULTS

The effectiveness of chemical treatment with hydrated lime in reducing pollutant levels for heat treatment recycle liquors was variable. Phosphorus, for example, was almost totally removed with relatively small lime dosages. On the other hand,

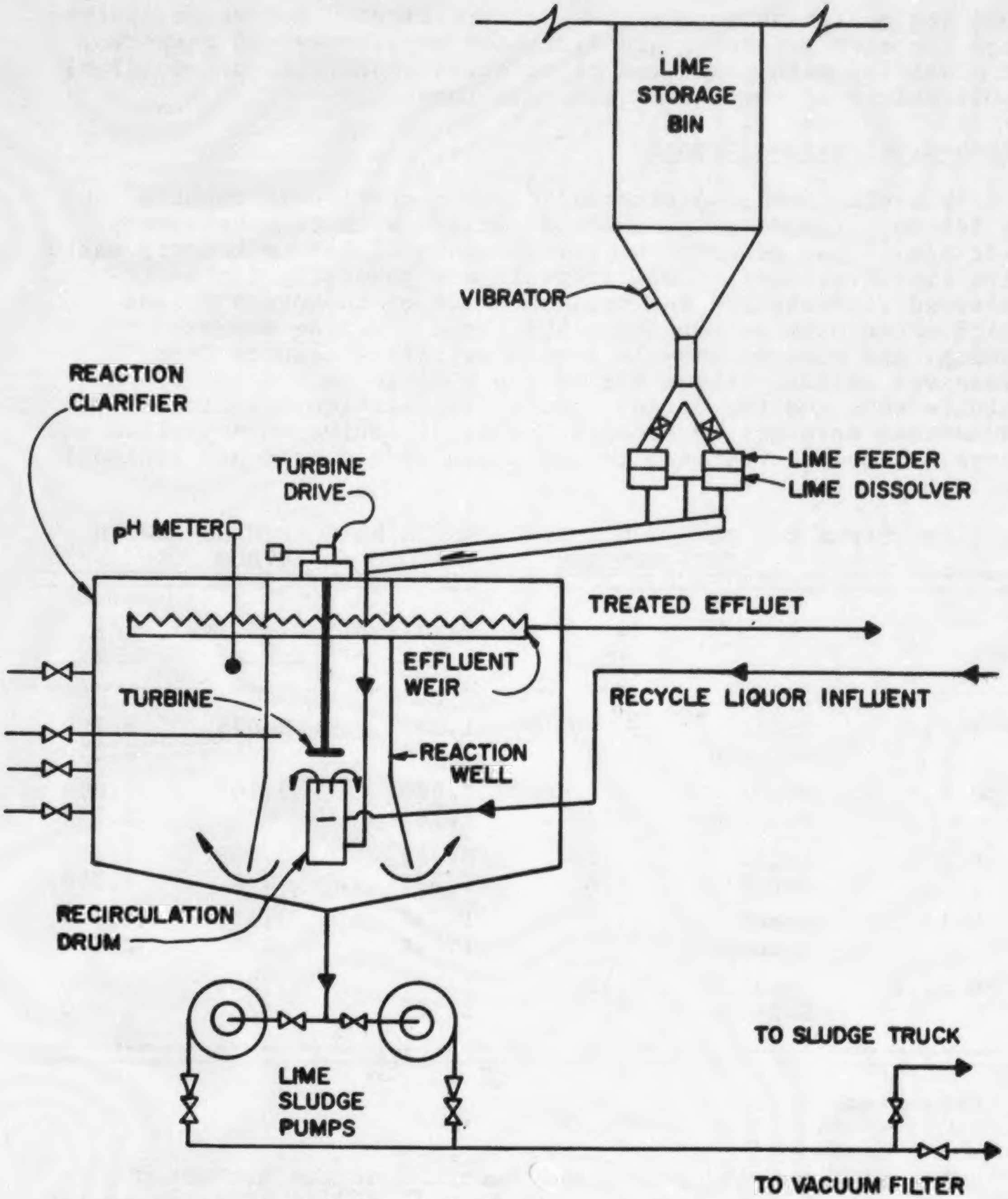
LIME STORAGE BIN
VIBRATOR
REACTION CLARIFIER
LIME FEEDER
LIME DISSOLVER
TURBINE DRIVE
pH METER
TREATED EFFLUET
EFFLUENT WEIR
RECYCLE LIQUOR INFLUENT
TURBINE
REACTION WELL
RECIRCULATION DRUM
LIME SLUDGE PUMPS
TO SLUDGE TRUCK
TO VACUUM FILTER

Figure 5. Schematic of chemical treatment facilities.

BOD_5 was resistant to the chemical treatment. Removal efficiencies for each parameter are discussed separately and compared, if possible, with plant and pilot scale industrial or municipal applications of wastewater lime treatment.

Biochemical Oxygen Demand

Buzzell(9) and Horstkotte(10) have previously reported up to 74% BOD_5 removals in municipal sewage with lime treatment. Eldridge(8) has reported BOD_5 reductions of 55% in tannery waste with lime treatment. BOD_5 removals are generally linked to improved flocculation and sedimentation of suspended solids which contribute to the total BOD_5 load. Unlike domestic sewage, the BOD_5 in recycle liquor primarily results from dissolved solids. About 95% of the BOD_5 in decant liquor is soluble BOD_5 and therefore, simple flocculation, precipitation mechanisms were not expected to be as effective when applied to recycle liquor. The results are shown on Figure 6 and listed in Table 8.

TABLE 8. BOD_5 CONCENTRATIONS IN RECYCLE LIQUOR WITH LIME TREATMENT AT VARIOUS pH LEVELS

		Biochemical Oxygen Demand, mg/l			
Run:		A	B	C	D
*pH 5.5	Total	1,580	1,950	3,675	3,700
	Soluble	N/A	1,860	N/A	3,050
pH 8.5	Total	N/A	1,900	3,100	2,800
	Soluble	N/A	1,750	N/A	2,500
pH 9.5	Total	1,250	1,750	3,200	2,580
	Soluble	N/A	1,700	N/A	2,250
pH 10.5	Total	1,275	1,550	3,300	2,400
	Soluble	N/A	1,540	N/A	2,600
pH 11.5	Total	1,150	1,340	3,300	2,390
	Soluble	N/A	1,200	N/A	2,450

* Untreated

The maximum BOD_5 reductions occurred at the highest pH. BOD_5 removals varied from 10-35% at pH 11.5. In addition to the precipitation of suspended BOD_5, minor entrainment and/or absorption of BOD_5 contributed to the BOD_5 which was extracted from the solution.

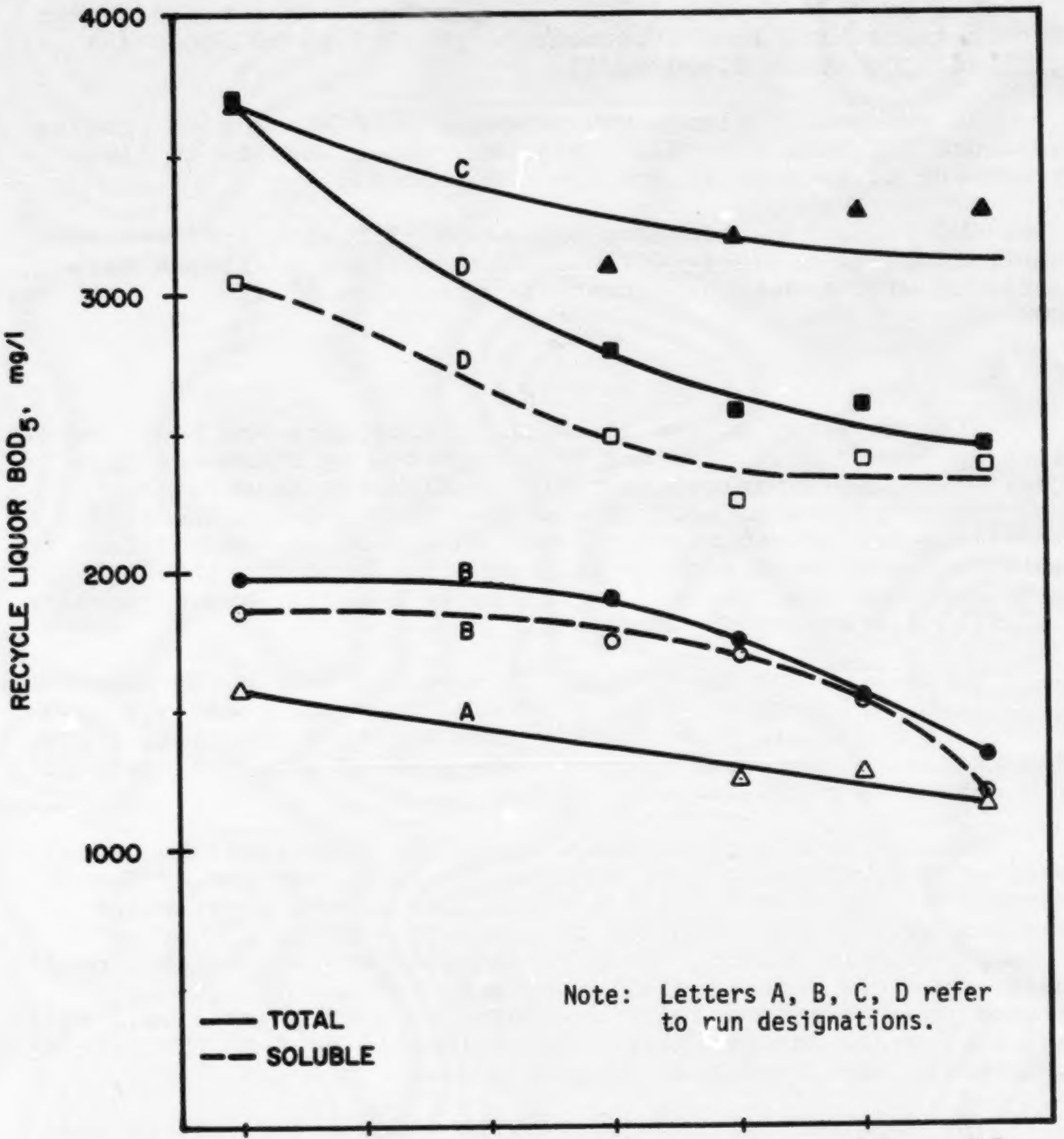

Figure 6. Results of lime treatment on recycle liquor BOD_5 concentration.

Chemical Oxygen Demand

Bennett(14) reported COD removals from anaerobic digester supernatants with lime treatment to pH 11.3 to be about 48% (initial COD about 5,400 mg/l).

At the Mentor plant, COD removals were similar to results obtained for BOD_5 removals. Figure 7 shows results of lime treatment of recycle liquor for COD removal.

COD reductions averaged 33% at pH 11.5 with influent concentrations of 2,840-14,400 mg/l. Reductions of 11-38% were achieved with treated effluents in the range of 1,900-11,800 mg/l COD.

Phosphorus

The chemistry of the reaction of phosphate and heavy metals such as iron and calcium has been reported by Stumm and Morgan.(14) They explained that the equilibrium between the soluble complexes of calcium and phosphate and the insoluble complexes are pH dependent. Given an excess of calcium in solution, complexes such as calcium orthophosphate ($CaHPO_4$) react to form the more stable insoluble species (hydroxyapatite, $Ca_5OH[PO_4]_3$) as the pH increases.

Buzzell(9) and Horstkotte(11) reported phosphate reductions from 11.5 mg/l P to 2.0 mg/l P (Marlbough, Mass.) and 9.4 mg/l P to 0.96 mg/l P (Contra Costa County Sanitary District, CCCSD, San Francisco Bay area), respectively, using lime treatment of raw sewage at pH 11.5.

Results from a pilot plant operation utilizing lime treatment of anaerobic digester supernatant were reported by Bennett.(13) The phosphorus concentrations of the supernatant liquors studied were similar to those of recycle liquor as studied in this report. From an initial phosphorus level of 141 mg/l, removals were studied at pH 9.6, 10.7, and 11.5. The liquor concentrations after treatment were 27.3 mg/l, 26.0 mg/l, and 18.7 mg/l, respectively. Approximately half of the remaining phosphorus was present as polyphosphates.

The chemistry of lime in recycle liquor, however, is complicated by competing reactions such as calcium carbonate formation and humic acid neutralization. In addition, some of the phosphorus is not available in a form that will react with lime (organically bound phosphorus).(15) At pH 8 and greater, most of the phosphorus remaining in solution is of the latter type since the solubility of the hydroxyapatite is less than 1 mg/l.(14)

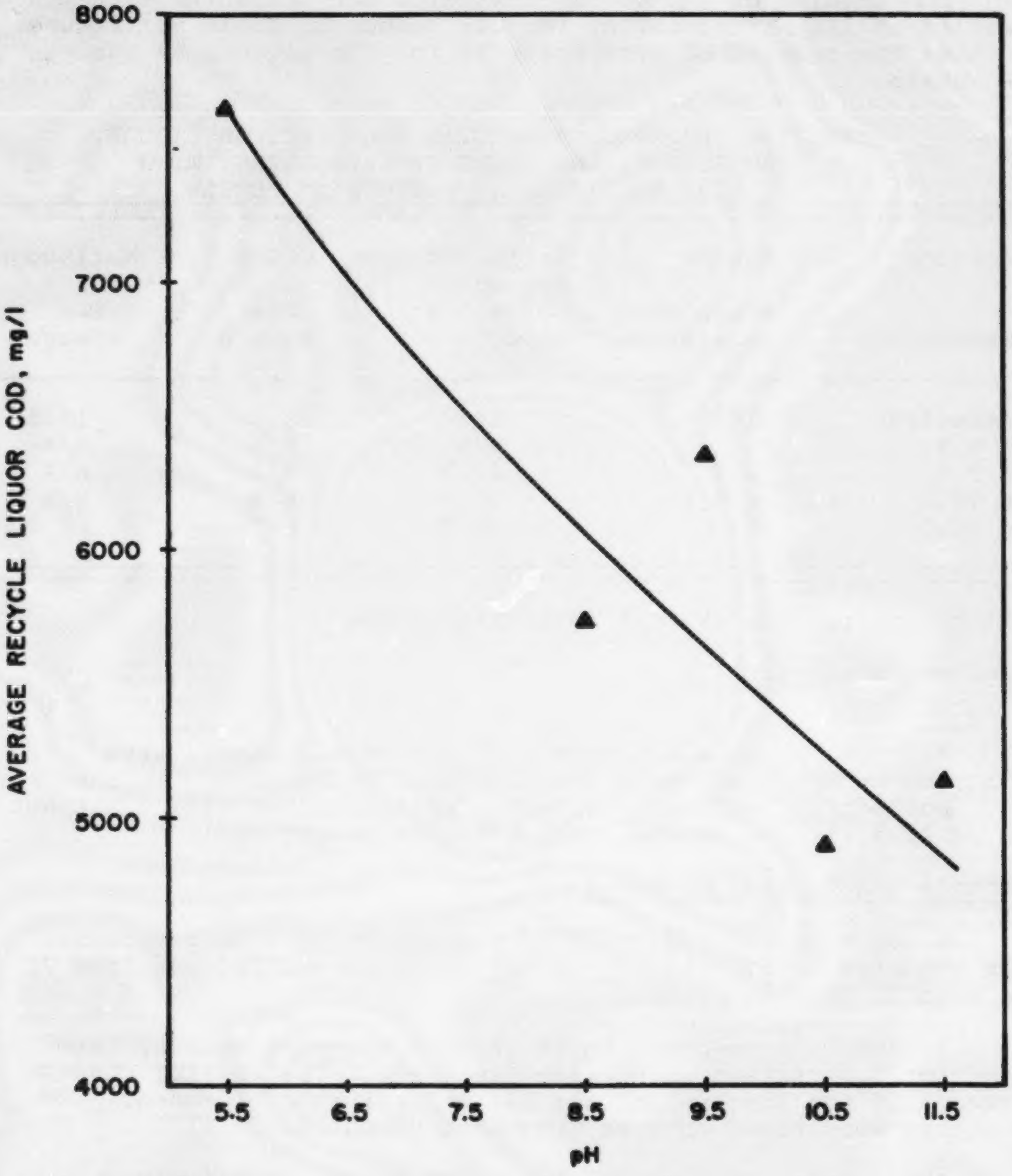

Figure 7. Results of lime treatment on recycle liquor COD concentration.

The results of the previous studies are presented with the results of lime treatment of recycle liquor in Table 9. Figure 8 shows the removal of phosphorus in recycle liquors at various pH levels.

TABLE 9. PHOSPHORUS REMOVAL FROM RECYCLE LIQUOR, RAW SEWAGE, AND DIGESTER SUPERNATANT WITH LIME TREATMENT AT VARIOUS pH LEVELS

Location:	Mentor	Irvington	CCCSD	Marlbough
Wastewater:	Recycle Liquor	Anaerobic Digester Supernatant	Raw Sewage	Raw Sewage
Untreated	195	141	9.4	11.5
pH 8.5	11.7	N/A	N/A	N/A
pH 9.5	2.4	27.3	N/A	N/A
pH 10.5	0.8	26.0	N/A	N/A
pH 11.5	0.0	18.7	0.96	2.0

All concentrations as mg/l total phosphorus

N/A, not available

Average phosphorus removals of 99% were achieved with influent phosphorus levels ranging from 70-270 mg/l. In one full scale test, 7.0 mg phosphorus remained after lime treatment to pH 11.5 with an initial concentration of 190 mg/l.

Ammonia and Organic Nitrogen

A 24% nitrogen reduction in raw sewage by lime treatment was reported by Buzzell.(9) Total nitrogen was reduced from 71 mg/l to 54 mg/l at pH 11.0.

Bennett(14) reported a 37% organic nitrogen removal from digester supernatant using lime treatment. The initial concentration of the supernatant was 282 mg/l organic nitrogen. Removals were based on lime treatment to pH 10.7.

The results of chemical treatment of recycle liquor with lime is shown on Figure 9. Average removals of ammonia nitrogen and organic nitrogen at pH 11.5 are 30% and 69%, respectively, and are listed in Table 10.

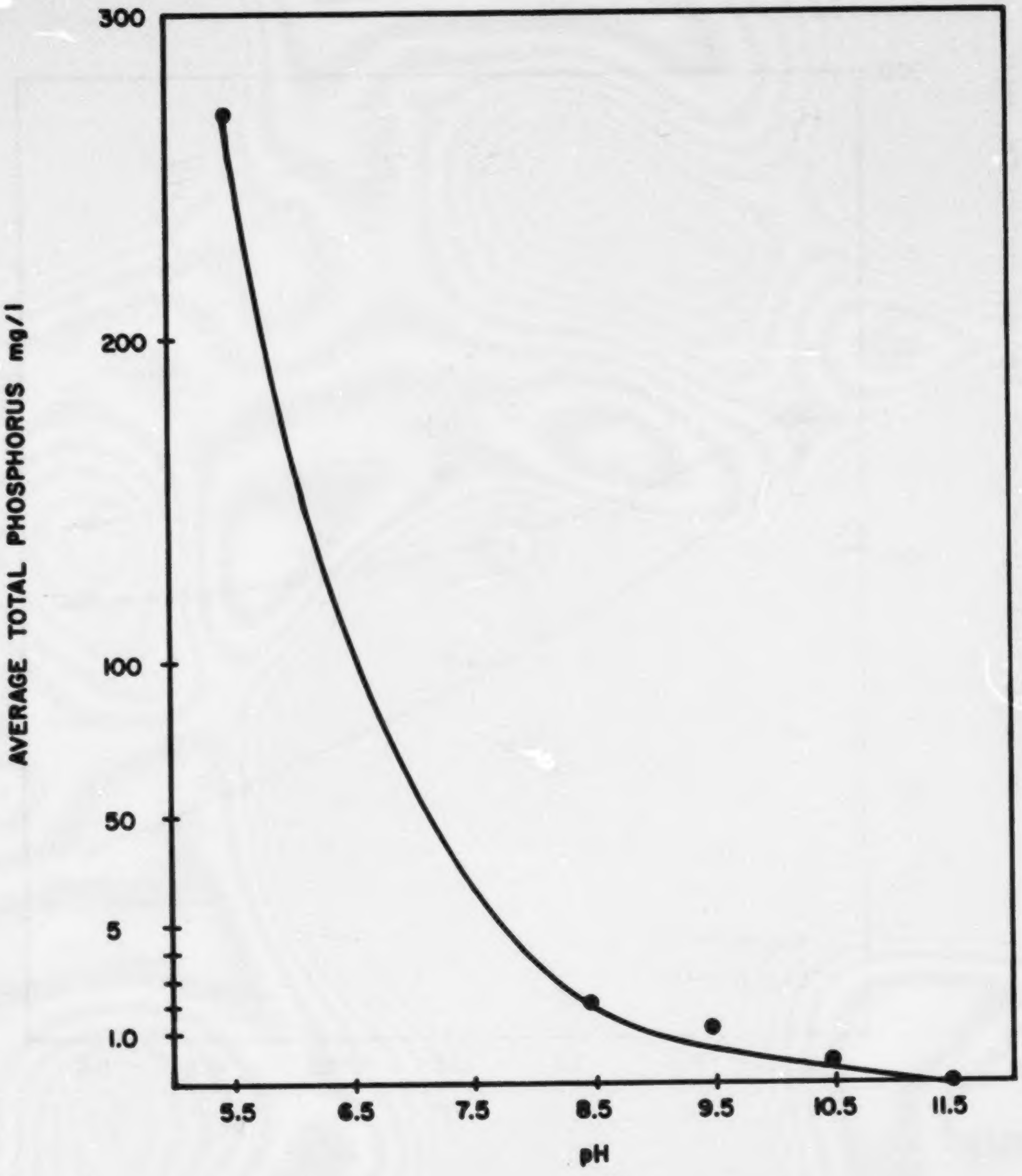

Figure 8. Results of lime treatment on recycle liquor average total phosphorus concentration.

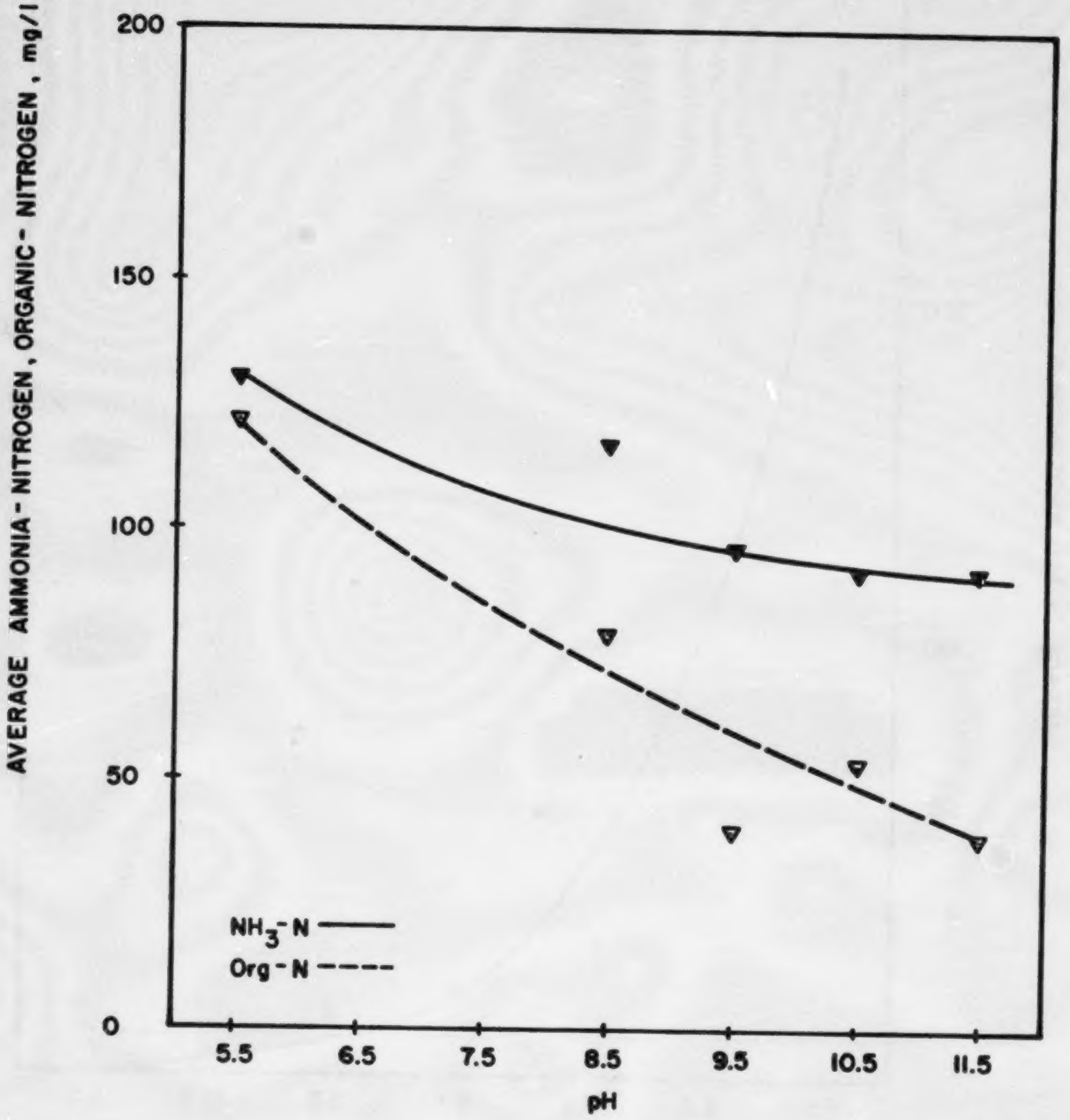

Figure 9. Results of lime treatment on recycle liquor average ammonia-nitrogen and organic-nitrogen concentrations.

TABLE 10. NITROGEN REMOVALS FROM RECYCLE LIQUOR WITH LIME TREATMENT AT VARIOUS pH LEVELS

	Ammonia Nitrogen, mg/l		Organic Nitrogen, mg/l	
	Average	Range	Average	Range
Untreated	129	(104-160)	122	(42-176)
pH 8.5	117	(117-118)	78	(34-123)
pH 9.5	95	(43-115)	40	(0-146)
pH 10.5	91	(45-129)	52	(0-156)
pH 11.5	91	(59-123)	38	(0-126)

The removal of ammonia nitrogen from recycle is about the same as the reduction achieved with raw sewage. Organic nitrogen reductions from recycle liquor is about the same as for anaerobic digester supernatant (84 mg/l and 104 mg/l removed, respectively).

The chemical composition of recycle liquor has been reported by Teletzke, et al.(15) The organic nitrogen sources in recycle liquor are largely proteins, free amino acids, free fatty acids, glycerides, sterol esters, choline and other minor components. Ammonia nitrogen in the liquor is a product of the decomposition of urea into ammonia and ammonium salts.(16) Chemical treatment of recycle liquor with lime converts all of the ammonium salts to free dissolved ammonia which remains in the liquor. Some ammonia vapor leaves the solution aided by mixing. Since mechanical mixing was used, a relatively low ammonia nitrogen removal was achieved. Greater ammonia nitrogen removal could be achieved if diffused air mixing was used.

Lime treatment of the recycle liquor was more effective in organic nitrogen removal. The mechanism for nitrogen reduction differs from the preceding case. One explanation is that proteins responsible for a large percentage of the organic nitrogen were coagulated by the action of the lime in a process called denaturation.(17) The residual free amino acids and low nitrogen bearing compounds such as choline and polyglycerides, etc., are not attacked by the action of lime. These compounds which are not entrained or adsorbed by the floc would account for the residual organic nitrogen.

Suspended Solids

As with other chemically assisted sedimentation processes, the lime clarification process is generally effective in reducing the concentration of suspended solids from wastewater. In lime treatment studies on raw municipal sewage (TSS=199 mg/l) reported by Horstkotte,(10) suspended solids removal of 79% to 41 mg/l was achieved at a lime dose of 500 mg/l calcium hydroxide, pH 11.5. Flow through the test facilities was about 4,920 cu m/day (1.3 MGD) during the studies. At a lower dose of lime to pH 11.0, the average effluent suspended solids were 50 mg/l (influent 206 mg/l TSS).

Lime treatment pilot studies with digester supernatant reported by Bennett(13) showed an average suspended solids removal of 64%, from 2,251 mg/l to 796 mg/l at pH 11.3. Removals were fairly constant at treatment levels pH 10.7-12.3. This suggests that the suspended solids capture was not pH dependent.

Lime treatment jar tests with recycle liquor at Mentor also showed the removal of suspended solids to be pH insensitive. Recycle liquor suspended solids were reduced to an average of 27 mg/l after lime treatment at pH 9.5 to 11.5 with an average initial TSS concentration of 475 mg/l.

Figure 10 shows the removal of suspended solids from recycle liquor at various pH levels after lime treatment.

Turbidity and Color

The increase of color in wastewater plant effluents has been attributed to the recycle of thermally conditioned sludge cooking liquors.(5)

Lime treatment for color reduction of paper mill bleach effluents has been successful in the kraft paper industry. At one kraft mill, consistent removal efficiencies of greater than 80% have been reported at lime dosages of 1,000 mg/l.(12) Haynes(12) reported kraft wastewater color reductions from 852 Pt-Co color units to 253 Pt-Co color units at pH 11.3, with a lime treatment dosage of 523 mg/l CaO. Wilson(11) also showed a color reduction in kraft wastewater in pilot plant studies. Lime treatment to pH 11.5 resulted in color reductions from 4,800 color units to 140 color units.

Boyle(5) reported that the Colorado Springs wastewater treatment plant final effluent had typical color readings of 60 to 100 color units and turbidities of approximately 10-20 JTU after the start-up of the heat treatment plant.

For recycle liquor, the removal of color and turbidity was similarly successful using chemical treatment with lime. Typical removals of color and turbidity are listed in Table 11. The results are comparable to those reported for the kraft paper industry and shown on Figure 11.

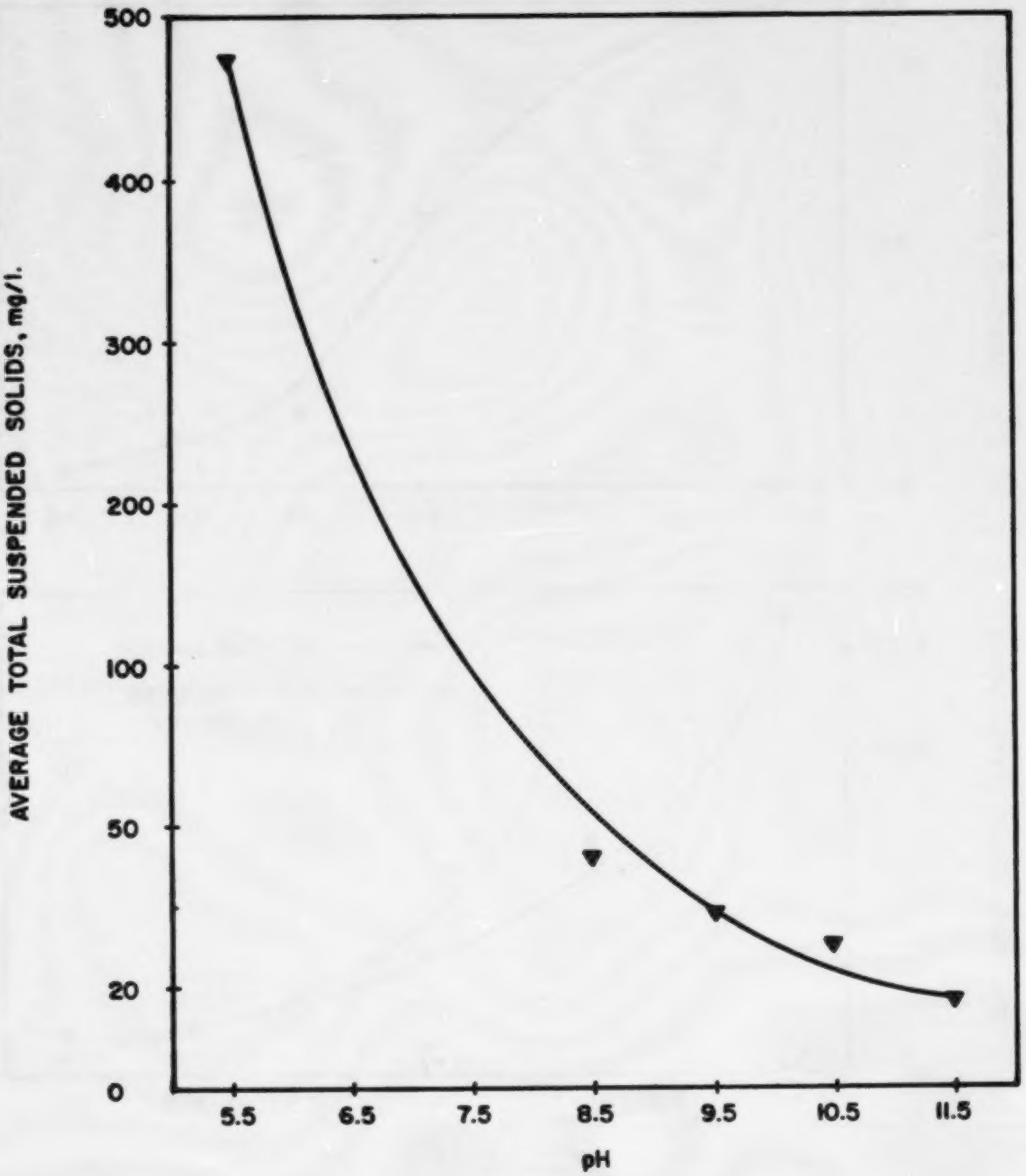

Figure 10. Results of lime treatment on recycle liquor average suspended solids concentration.

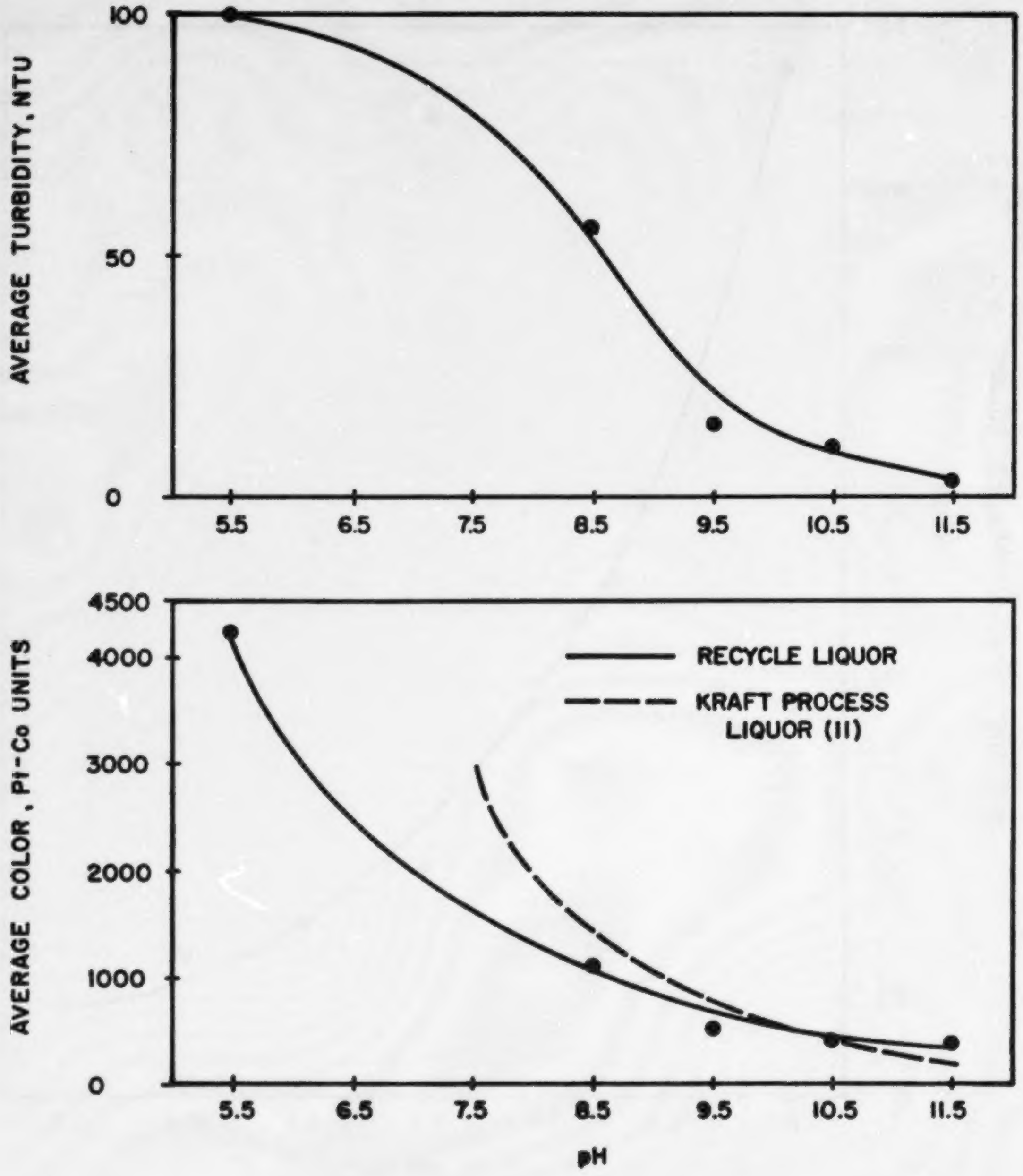

Figure 11. Results of lime treatment on recycle liquor color and turbidity levels.

TABLE 11. COLOR AND TURBIDITY CONCENTRATIONS IN RECYCLE LIQUOR WITH LIME TREATMENT AT VARIOUS pH LEVELS

	Average	Range
Initial pH		
Color, Pt-Co units	4,250	(3,000-6,000)
Turbidity, NTU	100	(100-110)
pH 8.5		
Color, Pt-Co units	1,100	(1,000-1,250)
Turbidity, NTU	55	(18-91)
pH 9.5		
Color, Pt-Co units	500	(200-800)
Turbidity, NTU	15	(6-24)
pH 10.5		
Color, Pt-Co units	410	(200-700)
Turbidity, NTU	10	(4-20)
pH 11.5		
Color, Pt-Co units	380	(150-650)
Turbidity, NTU	3	(2-4)

Average color removals at maximum lime dosage levels were 97% with color levels after treatment (pH 11.5) that ranged from 150-650 Pt-Co units. Average turbidity reductions of 97% were similarly experienced with turbidity levels after treatment that ranged from 2-4 NTU.

As illustrated on Figure 11, most of the color and turbidity abatement occurred after partial treatment to pH 9.5 with reductions of color and turbidity at 88% and 85%, respectively. The incremental removals achieved by additional lime treatment to pH 11.5 were smaller at 24% and 33%, respectively, indicating diminishing returns on further treatment.

As the data shown in Table 11 indicate, the treated liquor retained a yellow to amber tint even after high lime treatment. Similar residual color was reported by Haug, et al(6) in a study of anaerobic filtration of recycle liquor. Refractory organic compounds solubilized during the heat treatment process were imputed to be responsible for the residual color after treatment. Everett(18) stated that residual COD resistant to biological treatment was the cause of the liquor's color.

Filtering the lime treated recycle liquor was carried out to determine the nature of the residual color. Since the color passed through the filter, the coloring can be attributed to fine colloidal particles and dissolved materials. Color and turbidity removals of this fraction would then be limited to adsorption and entrainment in the lime floc.

Heavy Metals

Lime is widely used for removal of metals from wastewaters. Cadmium, trivalent chromium, copper, lead, nickel, and zinc all form hydroxides with lime. The solubility of these amphoteric metal hydroxides, although pH dependent, is generally low at all alkaline conditions.(19) Figure 12 shows typical metal concentration reductions achieved with lime treatment at various pH levels. The application of lime at any dose over pH 8.5 was sufficient to remove most metals. Table 12 summarizes the average heavy metal concentrations following lime treatment.

TABLE 12. AVERAGE HEAVY METAL CONCENTRATIONS IN RECYCLE LIQUOR WITH LIME TREATMENT AT VARIOUS pH LEVELS

Metal	Untreated	pH 8.5	pH 9.5	pH 10.5	pH 11.5
Cadmium, ug/l	300	15	13	13	13
Chromium, ug/l	800	26	21	16	16
Copper, ug/l	500	17	9	13	13
Lead, ug/l	1,100	160	140	130	160
Nickel, ug/l	500	37	31	36	39
Zinc, ug/l	900	34	17	20	13

The data show that the removal of metals from recycle liquor is essentially constant at any level of lime treatment for the pH range studied. Average removals of heavy metals after lime treatment (pH 8.5 or greater) were: 95% for cadmium, 97% for chromium and copper, 85% for lead, 93% for nickel, and 98% for zinc. Residual concentrations of cadmium, chromium, copper, nickel, and zinc after treatment were uniformly below 40 ug/l. Average lead concentrations after lime treatment ranged from 130-160 ug/l.

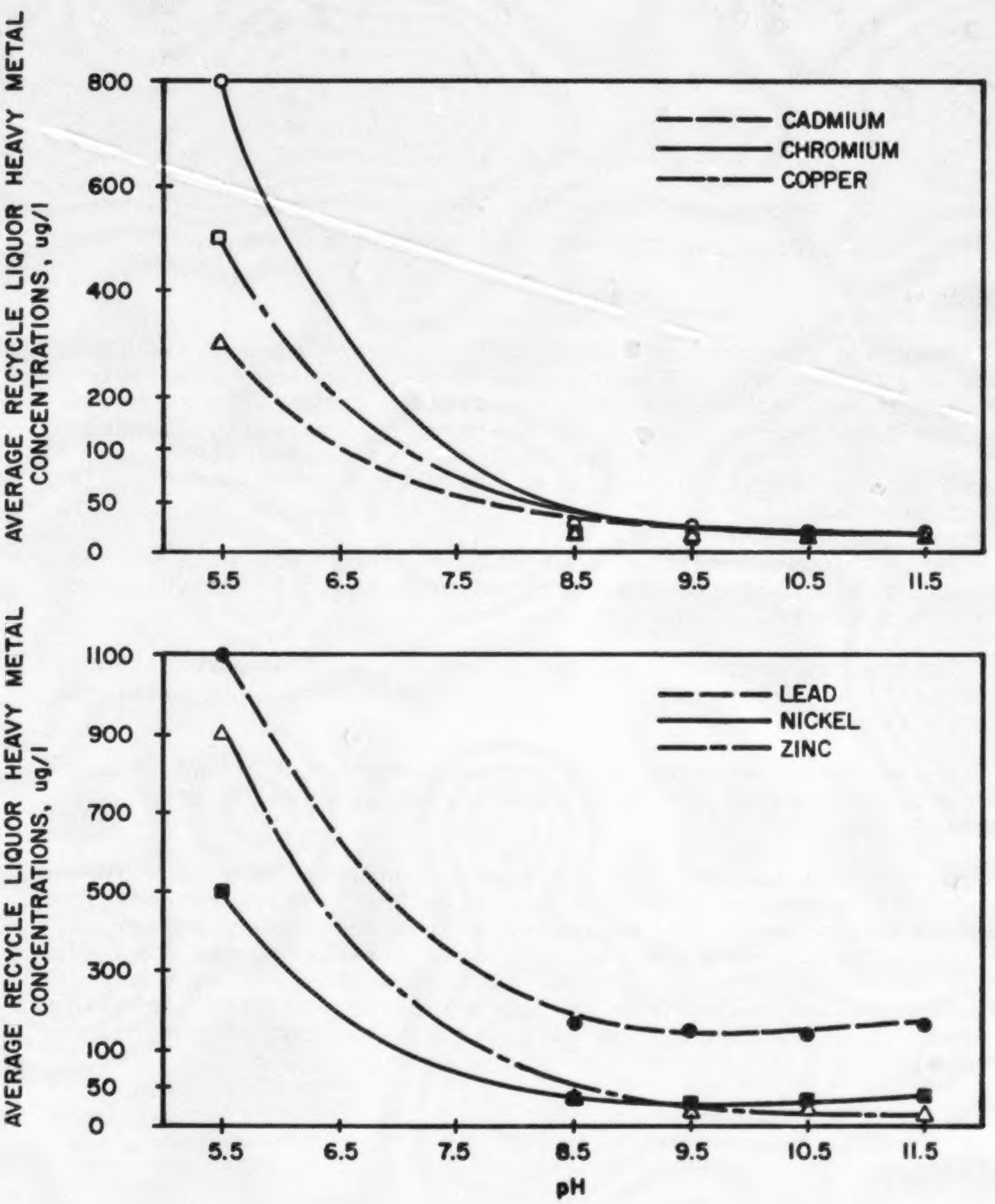

Figure 12. Results of lime treatment on recycle liquor heavy metal concentrations.

SECTION VI

BIOLOGICAL TREATMENT OF RECYCLE LIQUOR

GENERAL

Previous research on biological treatment of recycle liquors has been conducted using anaerobic digestion, anaerobic filtration, and activated sludge systems. Cooper(20) reported that 85% BOD_5 removals could be achieved by anaerobic digestion with a ten day detention time. Salotto, et al(21) also concluded that anaerobic digestion was a viable method of recycle liquor treatment.

Haug(6) concluded that anaerobic filters were well suited to the treatment of liquors produced from thermal conditioning of waste activated sludge.

Laboratory activated sludge processes were investigated by Everett(18) to determine the biodegradability of heat treatment recycle liquor.

Larger pilot studies were conducted by Erickson and Knopp(22) and Corrie(23) using the activated sludge process to treat recycle liquors.

Biological treatment of thermally conditioned sludge recycle liquors with a 10.9 cu m/day (2,880 gpd) high rate activated sludge process was evaluated at the Willoughby-Mentor wastewater treatment plant as a method of reducing the liquor's impact on the plant. BOD_5, COD, nitrogen, phosphorus, and suspended solids removals were determined to evaluate the effectiveness and benefits of the biological treatment of recycle liquors.

OPERATION AND SAMPLING

Facilities

A high rate activated sludge plant was used to evaluate the treatment of recycle liquors. A schematic of the facility is shown on Figure 13. Recycle liquor influent to the plant was drawn from a storage tank assuring a constant supply of recycle liquor. A positive displacement pump transferred the recycle

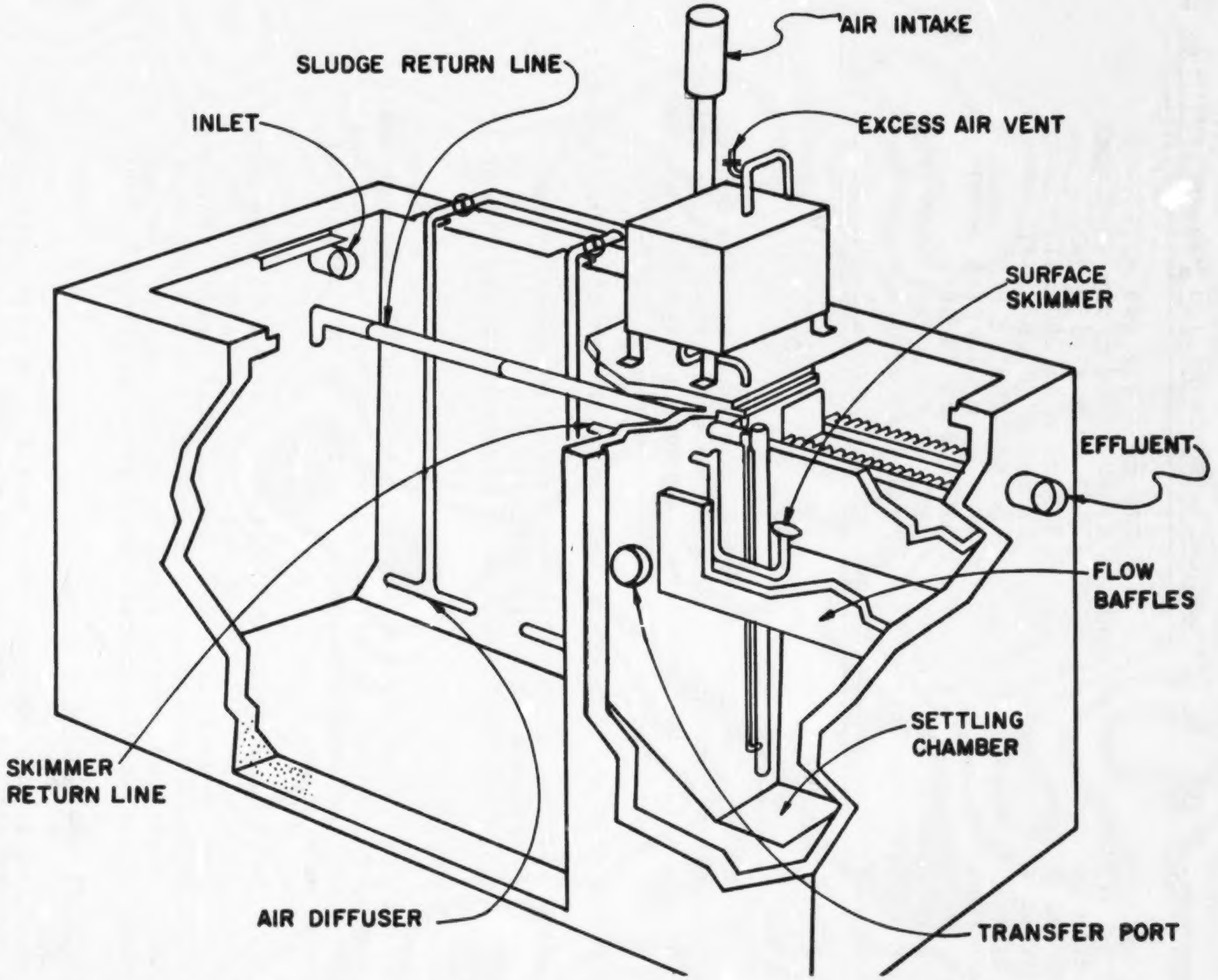
AIR INTAKE
SLUDGE RETURN LINE
INLET
EXCESS AIR VENT
SURFACE SKIMMER
EFFLUENT
FLOW BAFFLES
SETTLING CHAMBER
SKIMMER RETURN LINE
AIR DIFFUSER
TRANSFER PORT

Figure 13. Biological treatment facilities.

liquor to the aeration tank. The design specifications for the system are outlined in Table 13.

TABLE 13. BIOLOGICAL REACTOR DESIGN PARAMETERS

Storage tank	120 cu m (32,000 gal)
Recycle liquor transfer pump	5.5-27.3 cu m/day (1-5 gpm)
Aeration volume	11.9 cu m (3,150 gal)
Clarifier volume	4.5 cu m (1,200 gal)
Clarifier surface area	3.3 sq m (35.5 sq ft)
Aeration diffusers	Coarse bubble
Blower capacity	4.68 cu m/min (165 scfm)
Blower motor	3,728 watt (5 HP)
Clarifier skimmer (air lift)	max. 0.08 cu m/min (20 gpm)
Return sludge pump (air lift)	max. 0.23 cu m/min (60 gpm)

Sampling

Samples were collected five days a week by Lake County treatment plant personnel. Samples were analyzed by the plant's laboratory staff. Duplicate samples were analyzed by Burgess & Niple, Limited laboratory to insure analytical accuracy.

Three samples were collected daily at the following points:

1. Influent pump suction - untreated recycle liquor
2. Aeration tank - mixed liquor
3. Effluent weir overflow - treated recycle liquor

Target Conditions

Since the waste treated by this process had approximately ten times the BOD_5 of normal domestic sewage, the plant was operated at high rate loadings. The following operational criteria were used:

1. Organic loading to aeration, 1.6-2.4 kg BOD_5 per day/cu m (100-150 lb BOD_5 per day/1,000 cu ft)
2. F/M, 0.4-1.0 (kg BOD_5 per kg MLSS under aeration)
3. Mixed liquor suspended solids, 4,000-5,000 mg/l
4. Dissolved oxygen level in mixed liquor, 2-4 mg/l
5. Minimize SVI (obtain good settleability)

Start-Up and Operation

Initially, the package plant was filled with settled sewage. Return activated sludge from the main plant was used to seed the aeration tank. A dissolved oxygen level in the mixed liquor was maintained at 6-10 mg/l. The return sludge ratio was initially set at 30:1. Hydraulic detention time through the aeration tank was set at about 26 hr by controlling the introduction of settled sewage to 10.9 cu m/day (2,880 gpd).

After a two week acclimation period, recycle liquor was substituted as a feed stock to the reactor. Since the package plant influent was not gradually changed to the stronger recycle liquor, an additional two weeks were spent to acclimate the microorganisms to the new waste. After target conditions were established, the process performed satisfactorily. Sludge volume indices were consistently below 90.

RESULTS

General

Biological treatment was conducted in two phases to determine if treatment would be affected by changing the characteristics of the recycle liquor influent to the process. Recycle liquor for the first phase was produced from heat treatment of primary sludge at 150° C for 60 min. The second phase of the study utilized recycle liquor produced from heat treatment of primary sludge at 190° C. The activated sludge process was operated close to target conditions for three weeks and two weeks, respectively. The average mean cell residence time was 1.3 days for each phase.

Biochemical Oxygen Demand

Erickson(22) reported achieving BOD_5 reductions of 96% with Zimpro recycle liquor on a pilot scale. Treatment of recycle liquor diluted with domestic sewage was studied by Corrie.(23) He reported 98% BOD_5 reductions at 1.1 kg BOD_5 per day/cu m (68 lb BOD_5 per day/1,000 cu ft) loadings.

The high rate activated sludge process at Mentor achieved BOD_5 reductions exceeding 93% for both phases of the research. Figure 14 shows the influent and effluent BOD_5 in relation to the plant organic loadings and SVI during the total project period. Effluent BOD_5 averaged 86 mg/l in the first phase and 265 mg/l in the second phase. For the same periods, the average loadings were 1.9 kg BOD_5/cu m/day (120 lb BOD_5/day/1,000 cu ft) and 2.1 kg BOD_5/cu m/day (133 lb BOD_5/day/1,000 cu ft), respectively.

Chemical Oxygen Demand

Previous studies have shown that recycle liquor COD is substantially reduced by biological treatment with removals as high as 80-90%.(9) The study by Everett(18) shows a correlation between COD loading and removals. Research at Lake County tends

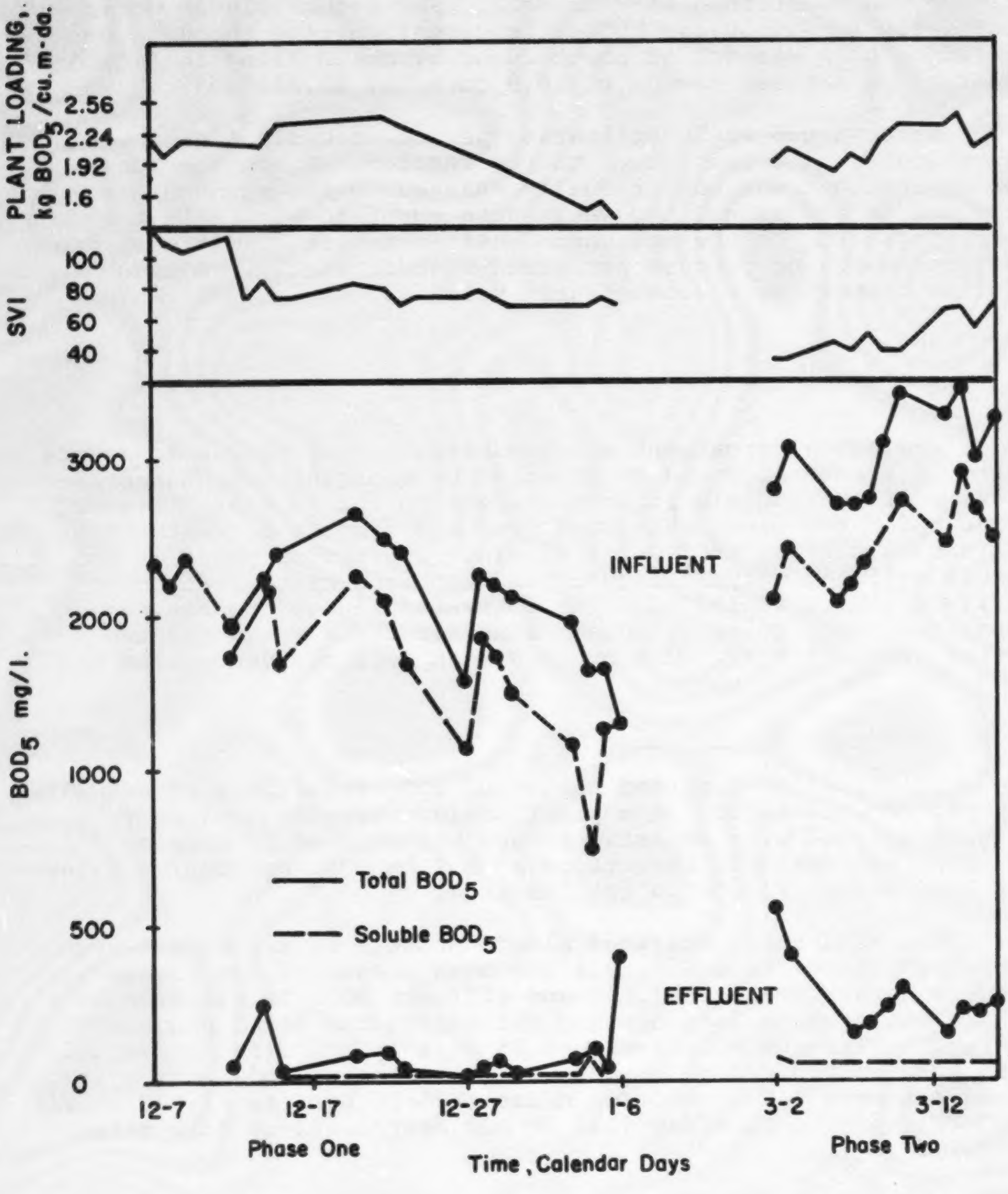

Figure 14. Influent and effluent BOD concentrations and organic loading rates for biological treatment of recycle liquors.

to reinforce that conclusion. Figure 15 shows the agreement with data from the biological treatment study at Lake County and findings by Everett. Table 14 summarizes the Lake County data for biological treatment phases. The data show that neither suspended nor soluble COD is preferentially removed and that a substantial portion of the total COD was resistant to biological attack. An average of 24% of the influent COD was not removed. This fraction of nonbiodegradable COD was more than three times larger than previously reported by Erickson.(22)

TABLE 14. COD REMOVALS ACHIEVED WITH BIOLOGICAL TREATMENT

Date	Total COD, mg/l Influent	Total COD, mg/l Effluent	Soluble COD, mg/l Influent	Soluble COD, mg/l Effluent	Removals Total	Removals Soluble
150° C Liquor						
12-27-77	3,480	1,120	N/A	N/A	68%	N/A
1-4-78	2,834	467	N/A	N/A	84%	N/A
190° C Liquor						
3-2-78	5,960	1,930	3,950	1,260	68%	68%
3-7-78	6,720	1,260	4,536	1,008	81%	78%
3-8-78	6,506	1,200	4,451	770	82%	83%
3-16-78	7,618	1,883	5,050	1,198	75%	76%

Nitrogen and Phosphorus

Nitrogen and phosphorus are nutrients necessary for growth of the microorganisms in activated sludge. Research by Helmers, et al(24) established that these nutrients are utilized by the activated sludge process in specific ratios. The average ratio of nutrient utilization by heterotrophic bacteria was reported as 100:6:1 for BOD:N:P removed. The utilization of nitrogen by nitrifying bacteria would be in addition to the carbonaceous nutrient utilization.

Studies by Corrie(23) and Erickson(22) on recycle liquor treatment by the activated sludge process confirmed the BOD:N:P relationship. Corrie reported a nutrient utilization of 100:6:1.4 and Erickson reported a BOD:N:P ratio of 100:4:1.4. Data from Lake County research on nitrogen and phosphorus removals correlated to BOD_5 removed is listed in Table 15.

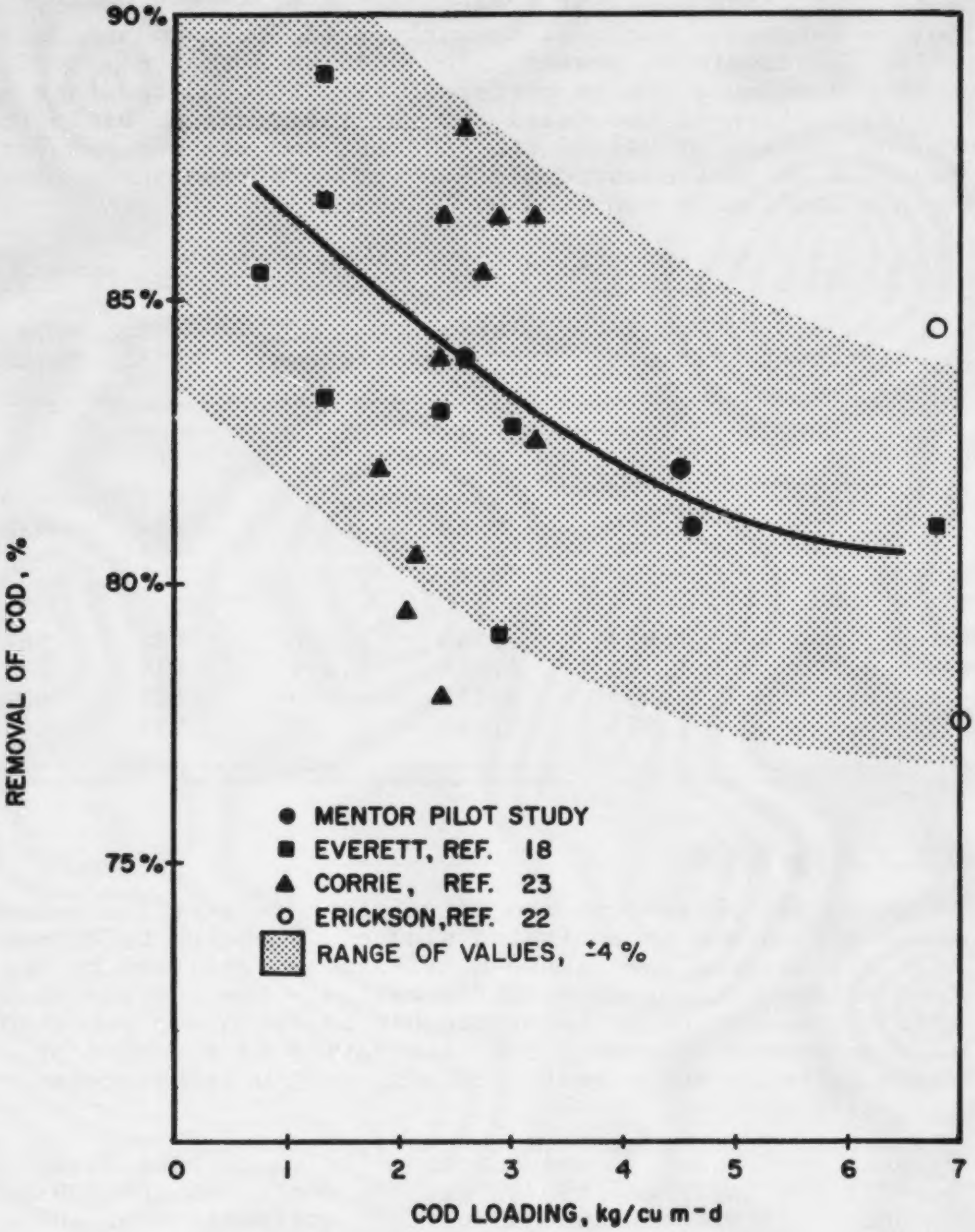

Figure 15. The effect of loading on COD removal from recycle liquor.

TABLE 15. NITROGEN, PHOSPHORUS AND BOD_5 REMOVALS WITH BIOLOGICAL TREATMENT

Run	12-15	12-27	1-4	3-2	3-8	3-16
BOD_5 removed, mg/l	2,464	1,700	1,584	2,240	2,648	2,775
Phosphorus, mg/l						
Influent	140	70	195	172	150	142
Effluent	10	4	110	41	14	15
Soluble Phosphorus, mg/l						
Influent	32	37	152	12	124	106
Effluent	0	3	-	9	12	5
Ammonia Nitrogen, mg/l						
Influent	140	118	115	101	162	165
Effluent	0.6	8.7	13	39	112	120
Organic Nitrogen, mg/l						
Influent	56	45	42	137	95	199
Effluent	9.5	7.6	18	106	28	104
Total Nitrogen Removed, mg/l	185.9	146.7	126	93	117	140
Removal per 100 parts BOD_5						
Total Nitrogen	7.5	8.6	8.0	4.2	4.4	5.0
Total Phosphorus	5.3	3.8	5.3	5.8	5.1	4.6
Soluble Phosphorus	1.3	2.0	-	0.1	4.2	3.6

The average BOD_5:N:P ratio was 100:6:2.2 for the above data considering only soluble phosphorus. The same ratio would be 100:6:2.5 for total phosphorus. Except for the higher phosphorus removals, the relationship is almost identical to earlier findings.

Average removals for phosphorus were 89%. Average ammonia nitrogen and organic nitrogen removals were 66% and 62%, respectively.

Suspended Solids

Overall suspended solids removal of 85-90% was achieved for the biological treatment of recycle liquor. Figure 16 shows the suspended solids data for both phases of the biological study. The concentration of suspended solids was reduced to an average of 100 mg/l for the first phase and 180 mg/l for the second phase. Suspended solids removals averaged 94% at a MLSS of 4,300 mg/l. Clarifier surface loading rates were 3.3 cu m/day/sq m (80 gpd/sq ft).

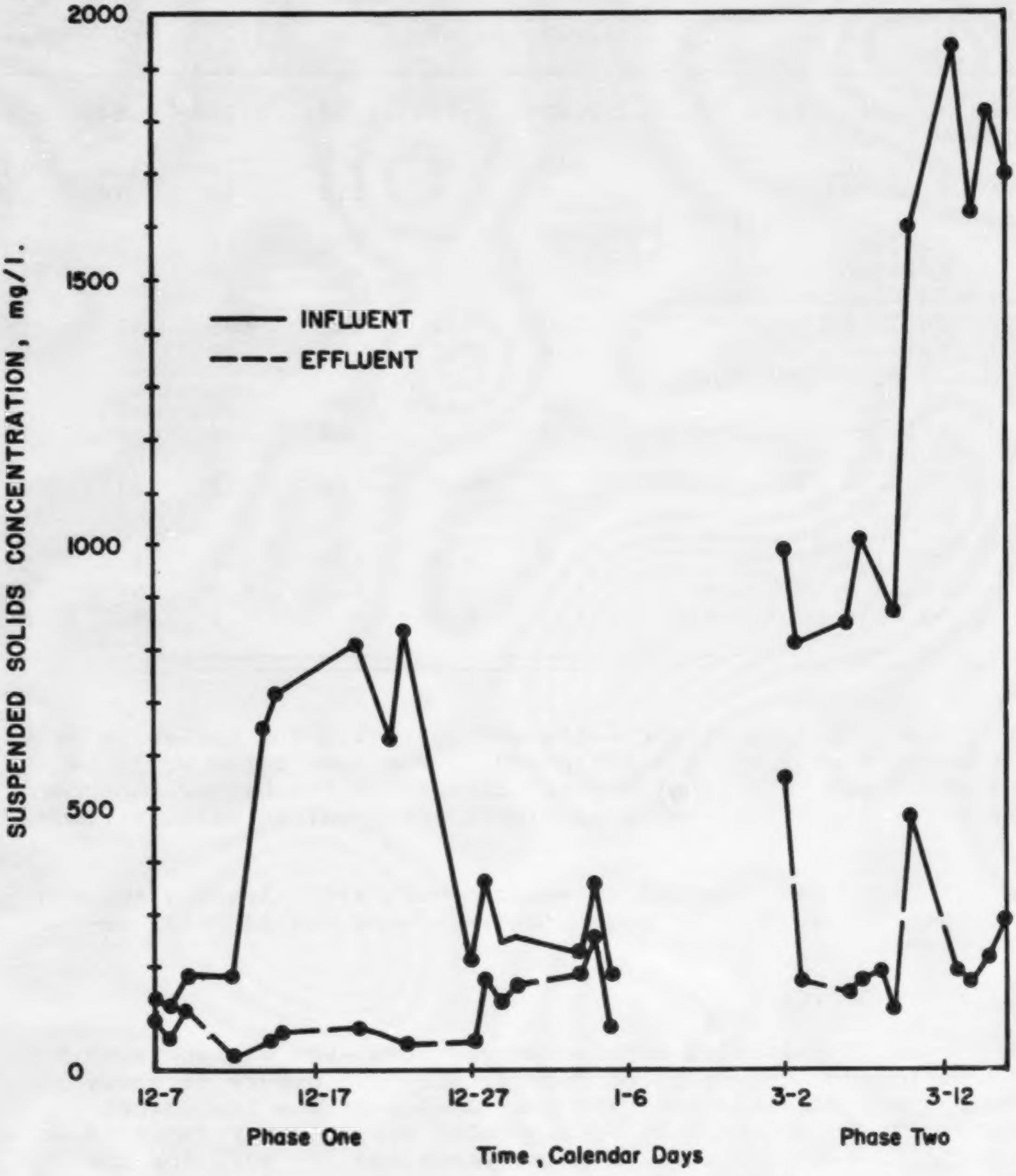

Figure 16. Recycle liquor influent and effluent suspended solids concentrations for biological treatment study.

Color and Turbidity

Although no laboratory data were taken to measure the color and turbidity of the biological treatment effluent, a visual observation could be made. Generally, during periods of good operation, the effluent was only slightly turbid. The color varied from almost colorless to a light yellow-amber.

Endogenous Decay Coefficient, k

The endogenous decay coefficient, or k rate, is used to predict the aeration requirements for wastewater stabilization and to predict the rate of BOD_5 utilization for carbonaceous bacteria in activated sludge processes. The value of k is the kinetic biochemical reaction rate for oxygen demand due to remaining BOD as it varies with time. The relationship can be expressed according to first-order reaction kinetics:(25)

$$dL_t/dt = -2.303k\ L_t$$

where L_t is the ultimate carbonaceous BOD remaining in the water at time, t and
k is the endogenous decay coefficient (base 10)

Integration of the equation yields an exponential function. The kinetic reaction rate, k, determines the shape of each curve. For example, a family of curves is shown on Figure 17, illustrating the effect of various values of k for a constant value of the ultimate carbonaceous BOD.

The k for domestic sewage has a typical value of 0.10 day^{-1}(25). Whereas, k for an industrial effluent from a soybean oil processing plant has been reported as 0.17 day^{-1}(26). Still higher values for k (faster oxygen uptake rates) have been reported by Erickson(22) for Zimpro recycle liquor at 0.40 day^{-1}.

The k rates were measured for the recycle liquor used in this study. Two other recycle liquors from Zimpro plants in Columbus, Ohio were also measured for comparison. The studies were conducted by measuring the BOD exerted by a recycle liquor sample daily for a 12 day period. The curves were extrapolated to obtain values for ultimate carbonaceous BOD. This was necessary because nitrifying organisms will cause interference after 12 days unless inhibited. (Note: Although not used in this study, this can be avoided by the use of the sodium salt of trichloromethyl pyridine (TCMP) available from Hach Chemical Company. TCMP is a nitrification inhibitor which will allow the full 20 day BOD test to be used free of interference.(27)) From BOD versus time plots, k-rates were determined graphically after a method by Thomas.(25)

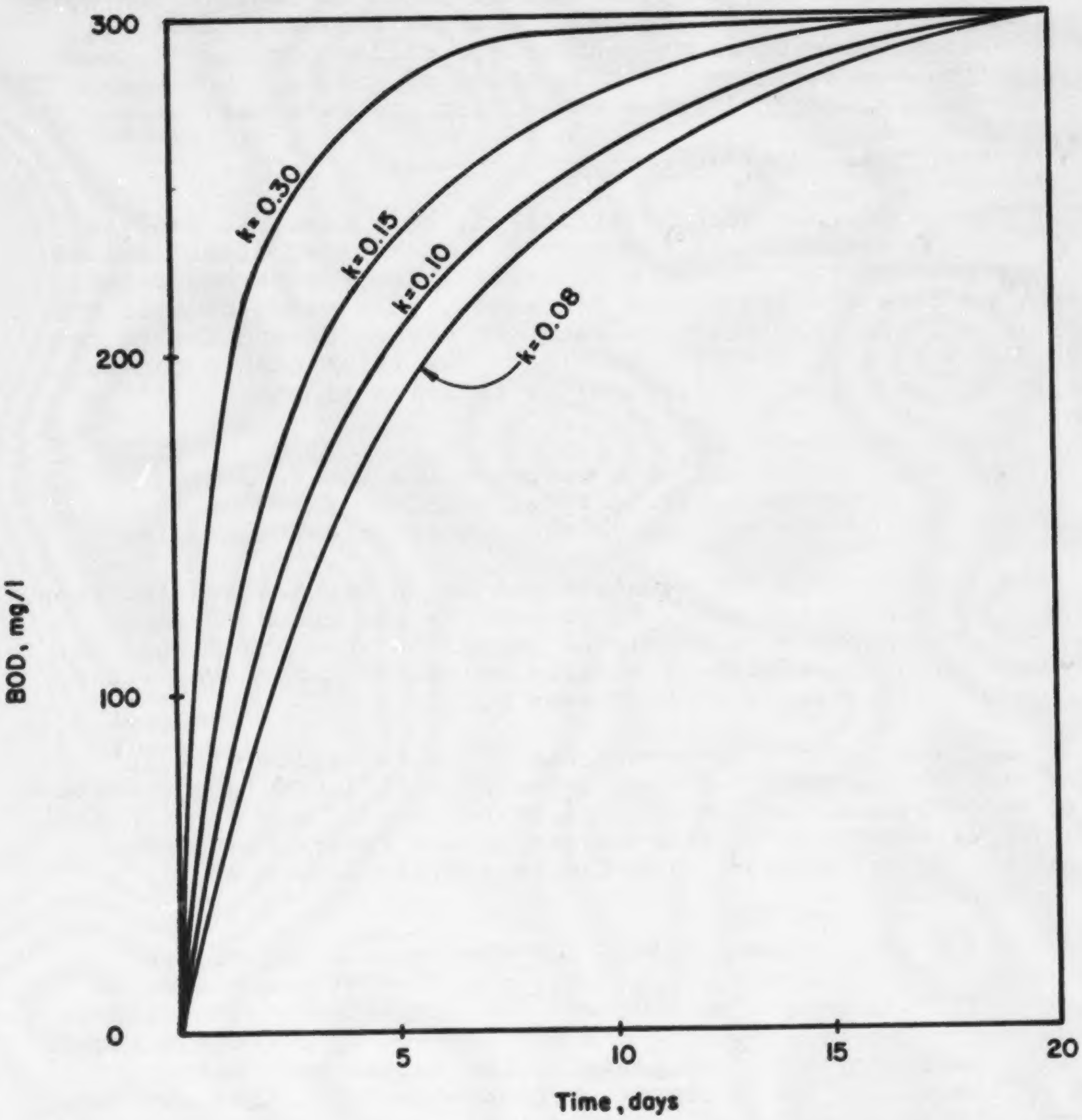

Figure 17. Endogenous decay curves.

The results of these studies are summarized in Table 16. The average endogenous decay coefficient for the recycle liquor was determined to be 0.13 day^{-1}.

TABLE 16. ENDOGENOUS DECAY COEFFICIENTS FOR SEVERAL RECYCLE LIQUORS

Origin	k, day^{-1}	Ultimate Carbonaceous BOD, mg/l
Mentor		
Decant	0.12	2,600
Decant	0.14	2,874
Decant	0.11	1,800
Decant	0.14	1,800
Jackson Pike		
Decant	0.17	4,000
Centrate	0.17	5,000
Southerly		
Decant	0.11	7,000

The k rates for these recycle liquors show that these liquors should have oxygen utilization rates only slightly higher than those for normal domestic sewage.

Sludge Production

Biological treatment of organic matter produces sludge as a by-product. The amount of that production varies with the type of waste treated. Cell growth coefficients (Y) are used to quantify that relationship. The coefficient is defined as the mass of solids produced by the biological action per unit mass of biological solids oxidized. For an activated sludge process, the coefficient is calculated:

$$Y = \frac{(\text{MLVSS})(V)+(\text{TVSS avg. eff.})(Q)}{(\text{BOD}_5\ i - \text{BOD}_5\ e)(Q)}$$

where: MLVSS = aeration tank mixed liquor volatile suspended solids

V = volume under aeration

TVSS avg. eff. = average total volatile suspended solids in the effluent

BOD_5 i = influent BOD_5

BOD_5 e = effluent BOD_5

Q = total daily flow

Cell growth coefficients reported in the literature(2,22) and coefficient determinations from biological treatment of recycle liquor at Mentor (calculated by the equation above) are summarized in Table 17. The values for recycle liquors are only slightly lower than those for municipal sewage. Biological treatment of recycle liquor will produce sludge in amounts equal to or less than sludge produced by the biological treatment of typical domestic sewage. The sludge produced by the biological treatment of recycle liquor requires stabilization and disposal like other waste activated sludges. This additional sludge handling must be included as an indirect cost inherent in heat treatment systems.

TABLE 17. CELL GROWTH COEFFICIENTS FOR VARIOUS WASTE LIQUORS

Description	Kg Volatile Solids Produced Per Kg BOD_5 Removed
Mentor, 150° C recycle liquor	0.49
Recycle liquor, (2)	0.6
Glucose liquor, (22)	0.42
Sewage, (22)	0.73

SECTION VII

RECYCLE LIQUOR TREATMENT ECONOMICS

GENERAL

Recycle liquor treatment is an indirect cost incurred with the sludge thermal conditioning process. This cost must be added to capital and operation and maintenance costs for heat treatment systems, along with costs for odor control. The chemical and biological treatment system cost estimates for recycle liquor processing are presented based on the preceding research experience at Lake County. The systems are scaled up to meet the needs of a larger heat treatment system with a capacity of 0.76 cu m/min (200 gpm) operated on a continuous basis. This is approximately the size of a system required to process the sludge generated from a 2.2 cu m/second (50 MGD) wastewater plant or 18,250 tonne dry solids/year (20,075 tons dry solids/year). Recycle liquor was assumed to have BOD_5 and TSS concentrations of 4,000 mg/l and 500 mg/l, respectively.

Each treatment system included the cost of sludge handling and disposal for those sludges which would be generated by the treatment process. Since lime sludge is difficult to dewater, a sludge processing and disposal method consisting of liquid handling and land application was chosen as a typical example. To be consistent, a biological waste activated sludge processing and disposal method, including aerobic digestion, liquid hauling, and land application, was selected for a cost comparison. The examples cited should also serve as a guide for cost evaluations of other systems that might be dictated by local conditions. No attempt, however, has been made in this report to develop the most cost effective treatment, sludge processing, and disposal method. Rather, these examples are intended to provide a basis for cost evaluation of overall heat treatment system economics.

The estimates are as of July 1978, and amortizations are for 30 years at 7%. Labor costs including benefits (such as sick leave, vacations, insurance, etc.) are at $8.50/hr. General operating labor is assumed to be three hours per shift for three shifts per day for both chemical and biological treatment processes. Power is calculated at $0.03/kwh ($200/HP-yr).

CHEMICAL TREATMENT COSTS

Chemical Treatment System

Recycle liquor chemical treatment system design data used to estimate capital costs are listed in Table 18.

TABLE 18. LIME TREATMENT SYSTEM DESIGN DATA

Recycle liquor processed	981 cu m/day (0.26 MGD)
Lime storage	91 kg (100 ton)
Augers, lime feeders, dissolving tanks (2 ea)	
Daily lime required as 73% CaO	2,356 kg/day (5,184 lb/day)
Reaction clarifier (400 gpd/sq ft)	60 sq m (648 sq ft)
Sludge pumps, 2 ea	20 cu m/min (150 gpm)
pH metering and control	
Lime sludge produced, dry solids	4,200 kg/day (9,240 lb/day)

Capital costs for the lime treatment system were based on a July 1, 1978 bid date and were as follows:

Lime feeders and storage	$ 45,000
Reaction clarifier	96,000
Control and pump building	190,000
Sitework, earthwork, and yard piping	40,000
Electrical and metering	43,000
Subtotal Construction Cost	$414,000
Engineering	44,000
Legal and Administration	22,900
Contingency	24,100
Total Project Cost	$505,000
Amortized Project Cost, pwf = 12.409	$ 40,700

Operation and maintenance costs were assumed to include land application of lime sludge as previously described, commercial grade hydrated lime at 73% CaO priced at $60.50/tonne ($55/ton) and power consumed at 45 kw (60 HP).

	Annual O&M Cost
Labor	$ 27,900
Maintenance	4,100
Chemicals	52,000
Power	12,000
Total O&M	$ 96,000

Lime Sludge Land Application

The disposal of lime sludge resulting from recycle liquor treatment was assumed to utilize land application of the liquid hauled by truck. The capital cost per sludge hauling vehicle was assumed to be $35,000, which was depreciated on a straight-line basis over a five year period.

The assumed hauling distance was 5-8 km (3-5 miles), round trip. Hauling time assumed 10 min to fill, 15 min to empty, and 17 min driving, or a total of 42 min per round trip. The truck volume was assumed to be 5.68 cu m (1,500 gal) per load. The cost of truck operations, excluding the driver and depreciation, was assumed to be $8.50 per operating hour. The truck driver labor rate was assumed to be $8.50 per hour, including overhead.(28)

Truck operation time was based on hauling on a five day per week basis, approximately 12 months per year, which results in the assumed 260 hauling days per year. The average volume hauled is 148.6 cu m/day (39,100 gal/day). Two trucks were assumed to be required, with a combined total of 26 loads per day.

Although it may be possible to obtain the use of farmland at no cost, e.g., on a voluntary basis, the land application economic analysis assumed that land would be purchased at a cost of $1,875 per hectare ($750/acre). Sludge application rates were assumed to be 22.4 dry tonne per ha per yr (10 tons/acre/yr). Land costs were amortized at 7% interest over a 30 year period. The land cost was defrayed by assuming a return of $123 per hectare ($50/acre), either as profit after farming expenses or as the rental value of the land.(28)

Capital and annual operation and maintenance costs for land application of lime stabilized sludge were calculated as follows and have been summarized in Table 19.

Lime Sludge Application Costs:

Land: 4.2 dry tonne/day x 365 days/yr = 1,533 dry tonne/yr (1,686 tons/yr)

(1,533 tonne/yr)/(22.4 tonne/ha/yr) = 68.4 hectare (169 acres)

68 hectare x $1,875/hectare/ 12.409 pwf = $12,239/hr

Truck depreciation: $35,000 x 2 = $70,000 capital

$70,000/5 yr = $14,000/yr

Truck driver: (130 cu m/day)/(8.1 cu m/truck/hr) = 16 hr/day

$8.50/hr x 2 shifts/da x 8 hr/shift = $136/day

$136/day x 260 days/yr = $35,400/yr

Truck operation: 2 trucks x 8 hr/day x $8.50/hr x 260 day/yr = $35,400/yr

Laboratory: = $1,500/hr lump sum

Land credit: 68.4 hectare x $123/hectare = $8,400

TABLE 19. COSTS FOR LAND APPLICATION OF LIME SLUDGE FROM CHEMICAL TREATMENT OF RECYCLE LIQUOR

Item	Total Annual Cost
Amortized cost of land	$12,200
Truck depreciation	14,000
Truck driver	35,400
Truck operation	35,400
Laboratory	1,500
Land credit	(8,400)
Total Annual Land Application Cost	$90,100*

*No credit taken for lime in sludge applied.

Chemical Treatment Cost Summary

The total cost for chemical treatment of recycle liquor including sludge handling and diposal is as follows:

Total Project Cost (excluding land disposal costs), from page 52	$505,000
	Annual Costs
Amortized Project Cost, from page 52	$ 40,700
Lime Treatment O&M, from page 52	96,000
Land Application, from Table 19	90,100
Total Annual Cost for Chemical Treatment System	$226,800

BIOLOGICAL TREATMENT COSTS

Biological Treatment System

Recycle liquor biological treatment system design data used to estimate capital costs are listed in Table 20.

TABLE 20. ACTIVATED SLUDGE TREATMENT SYSTEM DESIGN DATA

Recycle liquor processed	981 cu m/day (0.26 MGD)
Aeration tank (100 lb BOD/1,000 cu ft-day)	2,450 cu m (647,000 gal)
Final settling (600 gpd/sq ft)	40 sq m (432 sq ft)
Blowers, 3 @ 1,500 scf/lb BOD_5 ea	67,140 watt (90 HP)
Sludge pumps (return, waste, standby),ea	1.36 cu m/min (360 gpm)
Biological sludge produced, dry solids	2,830 kg/day (6,220 lb/day)

Capital costs for the biological treatment system were based on a July 1, 1978 bid date, and were as follows:

Aeration tank	$293,000
Final settling tank	54,000
Control and pump building	146,000
Sitework, earthwork, and yard piping	60,000
Electrical and metering	64,000
Subtotal Construction Cost	$617,000
Engineering	61,000
Legal and Administration	34,000
Contingency	36,000
Total Project Cost	$748,000
Amortized Project Cost, pwf = 12.409	$ 60,300

Operation and maintenance costs for the activated sludge treatment system, excluding aerobic digester operation and land application, were as follows:

	Annual Costs
Labor	$ 27,900
Maintenance	6,200
Power, 328 kw (440 HP)	88,000
Laboratory	1,500
Total Annual Cost	$123,600

Biological Sludge Stabilization

The waste activated sludge generated by the activated sludge treatment of recycle liquor must be stabilized prior to land application. An aerobic digestion system to stabilize 2,830 kg/day (6,220 lb/day) waste activated sludge at 1% solids designed for ten days detention time was used to estimate capital costs.

Description	Capital Cost
Aerobic digester, 2,832 cu m (0.75 MG)	$384,000
Control building including blowers	154,000
Sitework, earthwork, yard piping	65,000
Electrical	70,000
Subtotal Construction Cost	$673,000
Engineering	65,300
Legal and administration	36,900
Contingency	38,800
Total Project Cost	$814,000
Amortized Project Cost, pwf = 12.409	$ 65,600

Operation and maintenance costs for the aerobic digestion system were as follows:

Description	Annual Cost
Labor	$ 9,300
Maintenance	8,500
Power	26,000
Laboratory	1,500
Total Annual Cost	$ 45,300

Stabilized Biological Sludge Land Application

The disposal of aerobically digested sludge was assumed to utilize land application in a manner similar to that previously described for lime sludge land application. The same cost assumptions have been used as previously explained for chemical sludge application.

Aerobically digested sludge land requirements were assumed to be 46.1 ha (115 acres), allowing no solids reduction through the digester. Sludge concentration was assumed at 1% versus 4.5% for lime sludge.

Land cost was defrayed by a land credit of $123/ha ($50/acre) as before and a fertilizer credit of $8.03/tonne ($7.30/ton) dry sludge solids. The fertilizer credit was arbitrarily assumed to be 50% of the value published by Brown(29) based on a medium fertilizer market value and a low fertilizer content. The reduction was made to reflect resistance to accepting the sludge as fertilizer.

Stabilized biological sludge land application costs are summarized in Table 21.

TABLE 21. COSTS FOR LAND APPLICATION OF DIGESTED SLUDGE FROM THE BIOLOGICAL TREATMENT OF RECYCLE LIQUOR

Description	Annual Cost
Amortized cost of land	$ 8,400
Truck depreciation, 3 trucks	21,000
Truck drivers, 5/da	91,100
Truck operation, 268 day/yr	91,100
Laboratory	1,500
Land credit	(5,700)
Fertilizer credit	(8,300)
Total Annual Cost	$199,100

Biological Treatment Cost Summary

The total cost for biological treatment of recycle liquor including sludge stabilization, handling, and disposal was as follows:

Total Project Cost (excluding land disposal costs)	$1,562,000

	Annual Costs
Amortized Project Cost*	$ 125,900
Activated Sludge Process O&M	123,600
Aerobic Digester O&M	45,300
Land Application	199,100
Total Annual Cost for Biological Treatment System	$ 493,900

*Includes sludge stabilization

COMPARISON OF TREATMENT COSTS

The total annual costs for treatment of recycle liquor utilizing a chemical treatment system or a biological treatment system are summarized in Table 22.

TABLE 22. COMPARISON OF TOTAL ANNUAL CAPITAL AND ANNUAL O&M COST FOR CHEMICAL AND BIOLOGICAL TREATMENT SYSTEMS

	Chemical Treatment		Biological Treatment	
	Annual Cost	Annual Cost per Tonne*	Annual Cost	Annual Cost per Tonne*
Facilities				
Amortized project costs	$ 40,700	$ 2.23	$125,900	$ 6.90
Operating labor	27,900	1.53	37,200	2.04
Maintenance labor & materials	4,100	0.22	14,700	0.81
Chemicals	52,000	2.85	N/A	N/A
Power	12,000	0.66	114,000	6.25
Laboratory	N/A		3,000	0.16
Subtotal Facilities	$136,700	$ 7.49	$294,800	$16.16
Land Application				
Amortized cost of land	$ 12,200	$ 0.67	$ 8,400	$ 0.46
Truck depreciation	14,000	0.77	21,000	1.15
Truck drivers	35,400	1.94	91,100	4.99
Truck operation	35,400	1.94	91,100	4.99
Laboratory	1,500	0.08	1,500	0.08
Land credit	(8,400)	(0.46)	(5,700)	(0.31)
Fertilizer credit	N/A	N/A	(8,300)	0.45)
Subtotal Land Application	$ 90,100	$ 4.94	$199,100	$10.91
Total Annual Cost	$226,800	$12.43 ($13.67/ton)	$493,900	$27.07 ($29.78/ton)

*dry solids sludge feed to thermal conditioning systems

Comparison of total annual costs on a pollutant removal basis shows that biological treatment is more cost effective than chemical treatment. Since the removals for phosphorus and suspended solids were essentially the same for either process, treatment costs were compared based on annual removals of BOD_5 (recycle liquor annual load = 1,435 tonne BOD_5). Assuming 35% BOD_5 reduction for chemical treatment and 93% BOD_5 reduction for biological treatment, the costs for recycle liquor treatment were:

Chemical treatment - \$451.79/tonne BOD_5 removed
Biological treatment - \$370.09/tonne BOD_5 removed

Other biological treatment processes should be considered for recycle liquor treatment in order to make a more thorough analysis. In addition, many different sludge handling and disposal methods could be considered depending upon the initial treatment process and local conditions.

These alternate treatment process trains were not addressed in this report.

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